

Investigations into the HYDRODYNAMICS OF NORTH WEST BAY

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Being a thesis submitted in part fulfilment of
of the requirements for the Degree of Master
of Environmental Studies.

Environmental Studies
University of Tasmania

1977

PREFACE

Despite the fact that modern oceanography has been established since at least the nineteenth century, bays and estuaries appear to have been singled out for particular study only within the past two decades. Yet their ecological importance, within the marine complex, is completely disproportionate to their area. They are generally highly productive zones and thus a major source of nutrients for coastal communities; they serve as refuges for many freshwater and marine species; and most importantly they are frequently important nursery grounds for the infantile stages of a variety of marine species, many of which spawn and spend much of their adult life at sea, but return seasonally to the estuary.

Apart from their importance in the marine complex, bays and estuaries are undoubtedly amongst man's most valuable natural resources, being significant to human welfare in a number of diverse, and often conflicting, roles. Being semi-enclosed they provide natural harbours; they connect the oceans and the inland rivers so they are natural transportation centres; they commonly support important fisheries; they offer scope for a wide range of recreational pursuits; and they are often convenient repositories for waste disposal. It is in this latter role that man's impact on estuaries has been the most significant, for many of the world's major estuaries have become little more than a septic tank for the urban industrial complex.

The extent of man's pressure on these waters is well illustrated by the fact that, of the ten largest metropolitan districts in the world, seven border estuarine areas (New York, Tokyo, London, Shanghai, Buenos Aires, Osaka and Los Angeles). These cities contain over sixty million people and foster enormous industrial activity. Ironically, recent concern with environmental degradation has often only increased the pressure on waterways. For example, to satisfy clean air regulations many industries have introduced 'scrubbers', (the Electrolytic Zinc

Company plant at Risdon, Tasmania, is an example), the effect of which is not to eliminate pollution but to transfer the pollution load from the atmosphere to the waterways.

Estuaries are particularly vulnerable to human influences for, being a confluent for land drainage, they receive the impact of many human activities throughout an entire watershed. Dams, diversions, irrigations, agriculture, forestry, changes in run-off due to urbanisation, and a multitude of other activities all have an ultimate impact on the complex physical, chemical, and biological interactions that occur within an estuarine eco-system.

The physical processes that occur within estuaries have a strong influence on the development and continued viability of their eco-systems. In general, the most important of these physical factors are, the circulation, that is the patterns of mass transport and associated mixing processes such as turbulent diffusion and entrainment, and the resultant distribution of salinity. To a very large extent they control the dispersion and the rate of removal of contaminants; patterns of erosion and sedimentation; exogenous renewal of nutrients, oxygen, and larvae; and the distribution of estuarine biota.

Thus a detailed knowledge of the hydrodynamic characteristics of bays and estuaries is not only of extreme importance but also has many practical applications. To the ecologist and the marine scientist it is part of the key to understanding the distribution of estuarine flora and fauna. To the industrialist and the environmental engineer it is one of the essential elements in evaluating the capacity of any estuarine or marine environment to receive industrial or domestic wastes. It should also be an important parameter considered in the planning and construction of offshore, nearshore, and shoreline structures, and the design of effluent disposal systems.

Yet the importance of the complex role of estuarine circulation is often not appreciated. This appears to be particularly true of the Tasmanian situation where data on the hydrology and hydrodynamics of estuarine systems is sparse. The present lack of such information generated interest in carrying out a study into the circulation of a bay or estuary that is, or is liable to become, an area of environmental concern.

Due to signs of increasing pressure and development, North West Bay, an area in close proximity to Hobart, was chosen as the study area. Brief investigations of its environs were carried out by students of the Environmental Studies Centre in the third term of 1976. From these pilot studies it was obvious that little was known about the marine environment of North West Bay, a situation common to most Tasmanian estuaries. This stimulated the investigations that are documented in this report.

This report on the study carried out between February and November 1977 has been submitted as part requirements for the degree of Master of Environmental Studies and represents the culmination of two terms' work.

As with any research project to be completed within an extremely short time, the design of the field program for the study area was strongly influenced by weather conditions, availability of equipment, and limited manpower.

Hence within these constraints the broad aim of the study were to provide baseline hydrological and hydrodynamic data and guidelines for future studies in North West Bay and other estuarine environments in the region.

Many people helped in various capacities throughout the field investigations and in the compilation of this report. In appreciation we would like to gratefully acknowledge -

- . Dr. R. Jones, Dr. J. Norton, Dr. M. Nunez and Mr. P. Waterman who were supervisors for this project.
- . Mr. P. Waterman, Mr. I. Coombes and Mr. A. McGifford who performed the diving operations required.
- . The Marine Board of Hobart (Cpt. Lucas and Cpt. Christie) and Dr. N. Sanders for providing vessels for the meter mooring deployment operations.
- . Dr. J. Thompson of Sea Fisheries, Tasmania.
- . Mr. B. Healy of Department of Environment, Tasmania.
- . Dr. D. Ritz, Dept. of Zoology, University of Tasmania.
- . Mr. J. Best, Mr. R. Carroll and Mr. J. Russell for assistance in drafting and printing.
- . Ms. K. Davidson and Miss W. Buza for typing and other assistance.
- . Numerous friends who at various times assisted in field investigations.

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introduction

1. INTRODUCTION

This introduction gives a general overview of estuarine research in Tasmania, and considers the specific need for hydrological and hydrodynamic studies in North West Bay. It then outlines aspects of this study by considering the field program, its aims and objectives and concludes by discussing the structure of the report.

1.1 General

At present information on the hydrological and hydrodynamic characteristics of Tasmanian estuaries is sparse. Newell¹ has carried out some limited investigations with regard to the dispersal of pulp mill effluents in Hospital Bay (Huon estuary) which included rhodamine B dye dispersal studies, current measurements with a pritchard vane, and surveys of chlorinity, temperature and dissolved oxygen. Newell² has also estimated total transport and flushing times in the lower Tamar River, in this case in regard to a proposed wood chip plant some three miles upstream from Bell Bay. These estimates were based on some chlorinity surveys and a few float drift measurements made available by the Port of Launceston Authority.

Some limited information is also available on the Derwent River estuary although this is mostly in the form of salinity and temperature data and zooplankton studies scattered among a number of unco-ordinated investigations such as those of Rochford³, Guiler⁴, Ong⁵ and Taw^{6,7}, and some currently unpublished data. This information is not comprehensive enough to determine the circulatory patterns, although Ong⁵ concludes that there is some evidence to support a cellular circulation similar to that proposed by Rochford³. However, it should be noted that the replacement of the old Hobart pontoon bridge by the Tasman bridge in 1965, plus dam construction by the Hydro Electric Commission, may have altered the hydraulic regime of the estuary.

More information on the Derwent estuary is liable to be available in the future. The Southern Metropolitan Sewerage Study⁸ indicates that work presently being undertaken by Sea Fisheries should lead to a mathematical model of the circulation of the upper part of the Derwent estuary and to a better understanding of the transport of pollutants.

1.2 North West Bay

There has been concern raised in the past few years in regard to the plight of the Derwent estuary, and adjacent bays such as North West Bay. Bloom⁹ has analysed heavy metal concentrations and publicly warned "that the Derwent is one of the most polluted rivers in the world". The Southern Metropolitan Sewerage Study⁸ points out that valuable oyster beds have already been lost and that there may be a potential threat to commercial fishing in the loss of important estuarine nursery areas.

It expresses concern at the present lack of data in many areas which include the hydrology and hydrodynamics of the system. This situation may, in part, be due to the fact that the present Tasmanian Environmental Protection Act¹⁰ is specifically directed towards the restriction and control of emissions and discharges and does little to encourage research into the air and water bodies receiving these contaminants. Thus the current approach tends to be to set standards at the outfalls without any knowledge of the complex dynamics of the receiving waters or their capacity to assimilate effluents.

North West Bay is an area of some environmental concern. The small estuarine part of the bay is an area of ecological importance. Walker¹¹ regards it as faunally, florally and physically one of the most complete estuaries he has found in the state. The current pressure of population and industry is small but can be expected to grow in the future. For example, the Southern Metropolitan Master Planning Authority¹² amongst its strategy options, for the future development needs of Hobart, considered the Kingston/Blackmans Bay/North West Bay Catchment area as one of its options for a select growth area. It appears that this option was rejected because "Kingston/Blackmans Bay has developed quite rapidly and will

continue to attract a major share of new private sector development". Furthermore, at the time the project was initiated, future sewerage proposals for the area were unclear. It would now appear that a proposal to pump sewage to a new treatment plant at Blackmans Bay (see Figure 2.1) is strongly favoured. However this scheme may still pose some threat to the bay. The Southern Metropolitan Sewerage Study⁸ suggests that there may be some need for tertiary treatment or that the outfall be situated in sufficiently deep water to ensure adequate dilution "because of the proximity of sensitive estuarine areas in North West Bay".

These considerations stimulated interest in carrying out an investigation into the hydrology and hydrodynamics of this particular bay. In the context of this report, hydrology refers to the physical and chemical properties while hydrodynamics is concerned with the astronomical and meteorological forces acting on the water body (that is, the driving mechanisms).

1.3 Field Program

The field program commenced in February of 1977 and carried on until mid September, being most intensive during August when current meter investigations were being conducted. The times at which various observations were made are shown in Figure 1.1.

The design of the program was heavily dependent on constraints and resources, particularly manpower. Thus it was generally not possible to monitor variables simultaneously at different points in the study area until some continuous recording equipment was installed in August. This equipment consisted of a barograph, tide gauge and two Alekseev current meters.

Under these circumstances it was apparent that it would not be possible to construct a comprehensive picture of the circulation within the bay. Therefore the objectives of this study were directed towards determining specific aspects of the hydrodynamics of the area, for example, the nature of the driving mechanisms. In general it was only possible to measure one or two variables at specific times although a continuous time record of several variables was obtained during August.

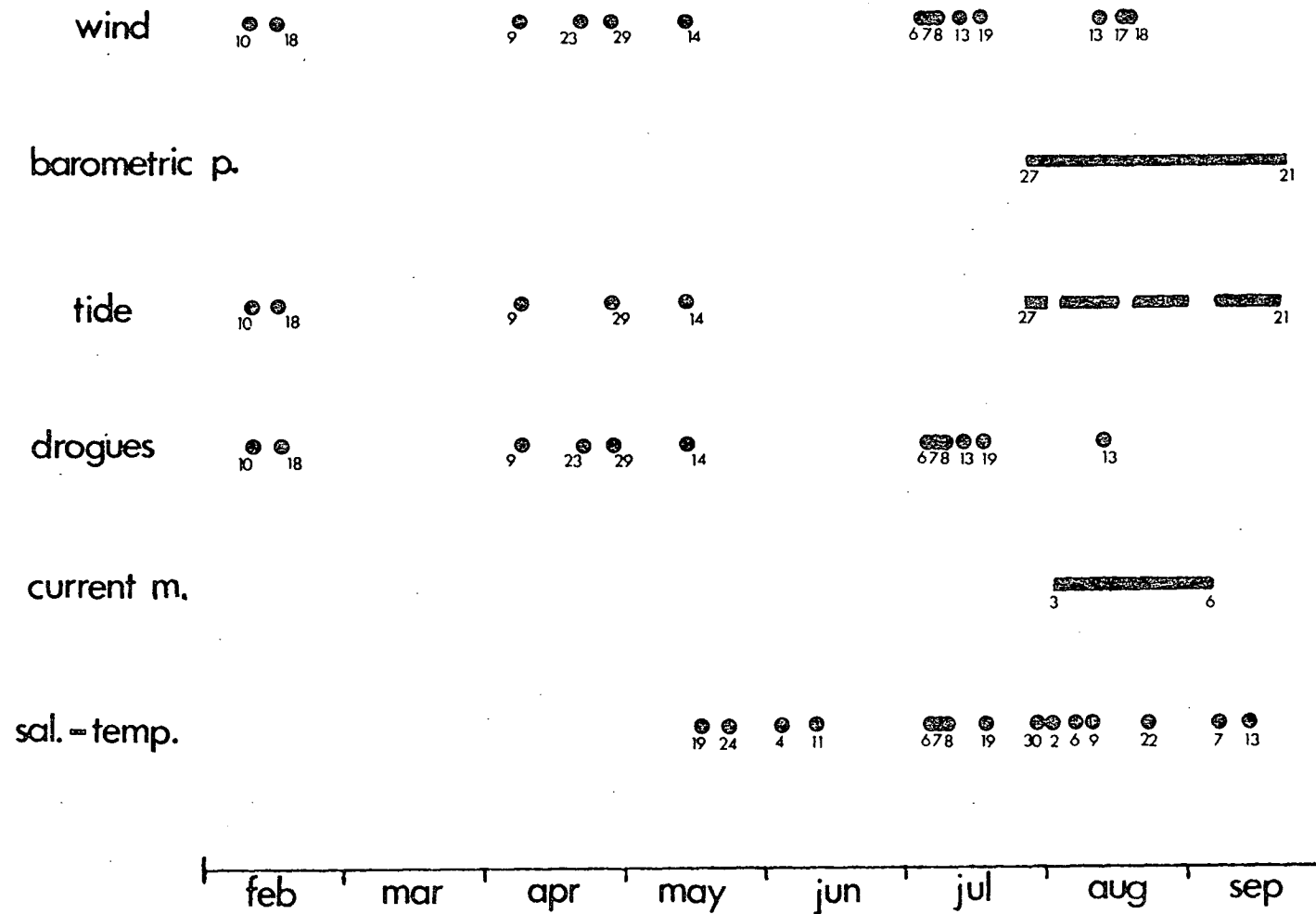


Figure 1.1 Study timetable

1.4 Aims and Objectives of the Project

The lack of information on the circulation within the bay (that is, the patterns of mass transport and the mixing processes) presented problems in planning the project. It was not clear which would be the most fruitful areas of investigation, what sampling rates would be required, and where the boundary of the study area should be.

Since the possibility of a detailed study of the overall circulatory patterns was excluded, it was decided that the main aim would be to conduct a broad scale study to obtain baseline data on which guidelines for future studies could be developed.

To achieve this aim the study was directed toward the following objectives -

1. To delineate the relative importance of the driving mechanisms from a spectral analysis of the current meter records.
2. To determine the significance of wind stress as a driving mechanism by the use of drogues.
3. From salinity-temperature measurements to ascertain the significance of the influence of other estuarine waters on North West Bay.
4. To gain some insight into the mixing mechanisms and rates of exchange between the bay and its adjacent waters.
5. If possible to construct some preliminary hypothesis of circulation patterns to provide a framework for future investigations.
6. To provide a summary of a range of available oceanographic techniques and methods, and assess the value of the techniques that were used in this study.
7. To make preliminary assessment of the possibility of mathematical modelling in North West Bay.

1.5 Structure of the Report

A number of features of this report require clarification as guidance for the reader.

Section 2 presents background information for the report and the physical aspects of the study area, with methodological considerations, study results and conclusions presented in the remaining sections.

Section 3, which presents methodological considerations and techniques essentially forms a self contained part. Thus the report could be read omitting this section without loss of continuity.

Some information and data, not easily accommodated in the main body of the report, has been presented in the Appendices.

It was not possible within the scope of this report to present an adequate review of the relevant literature. However a general bibliography covering texts and reports that were useful references in establishing the framework for this study is presented at the end of the report.

1.6 Summary

- . There has been little research into the hydrological and hydrodynamic aspects of Tasmania's estuaries.
- . At present the Tasmanian Environmental Protection Act does little to encourage research into these areas.
- . North West Bay is an example of an area of environmental concern and little is known of its ecology, particularly the hydrology and hydrodynamics.
- . This lack of information makes it impossible to construct specific research hypotheses. Hence this study has been directed towards the broad aims of providing baseline data around which future studies can be designed.

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2

characteristics of the study area

2. CHARACTERISTICS OF THE STUDY AREA

In this section the physical environment of North West Bay is briefly described to give the 'setting' in which the study was carried out.

The first part gives a general description of the study area. This outline is followed by a discussion of : the climate; rivers and their catchments; hydrography, tides and flushing; concluding with a discussion of some hydrological aspects.

2.1 General

North West Bay is a small trapezoidal shaped bay located in southern Tasmania some twenty two kilometres south of Hobart (see Figure 2.1). The 'study area' is defined by boundaries drawn at Dennes Point and Woodcutters Point and is shown in Figure 2.2.

The current population of the watershed is in the order of 2000 people, with the only significant centres of population being the small townships of Margate, Snug and Electrona. Much of the bay is presently bordered by undeveloped land and the environs retain an essentially rural character. Thus, being in the near vicinity of Hobart, the area offers considerable recreational potential which includes a number of beaches well suited for swimming.

The economy of the area is largely based on farming, small commercial enterprises, and some light industry such as fish processing. The only major industrial development is a carbide plant, located at Electrona, which employs about 170 people. However, some sections of the area can be expected to come under considerable pressure for development. These aspects, together with a review of the human environment, are considered in more detail in Appendix A.

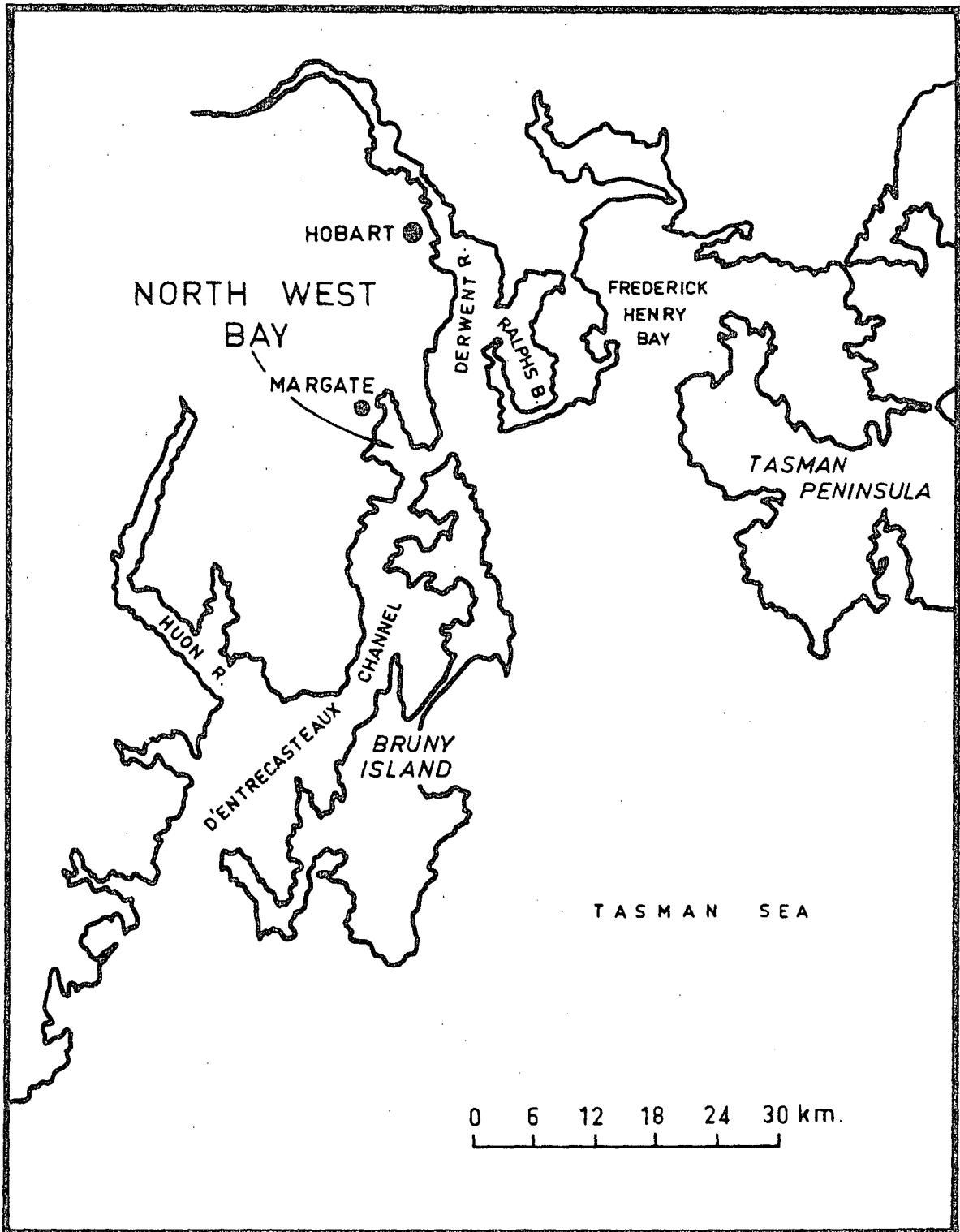


Figure 2.1 Location map

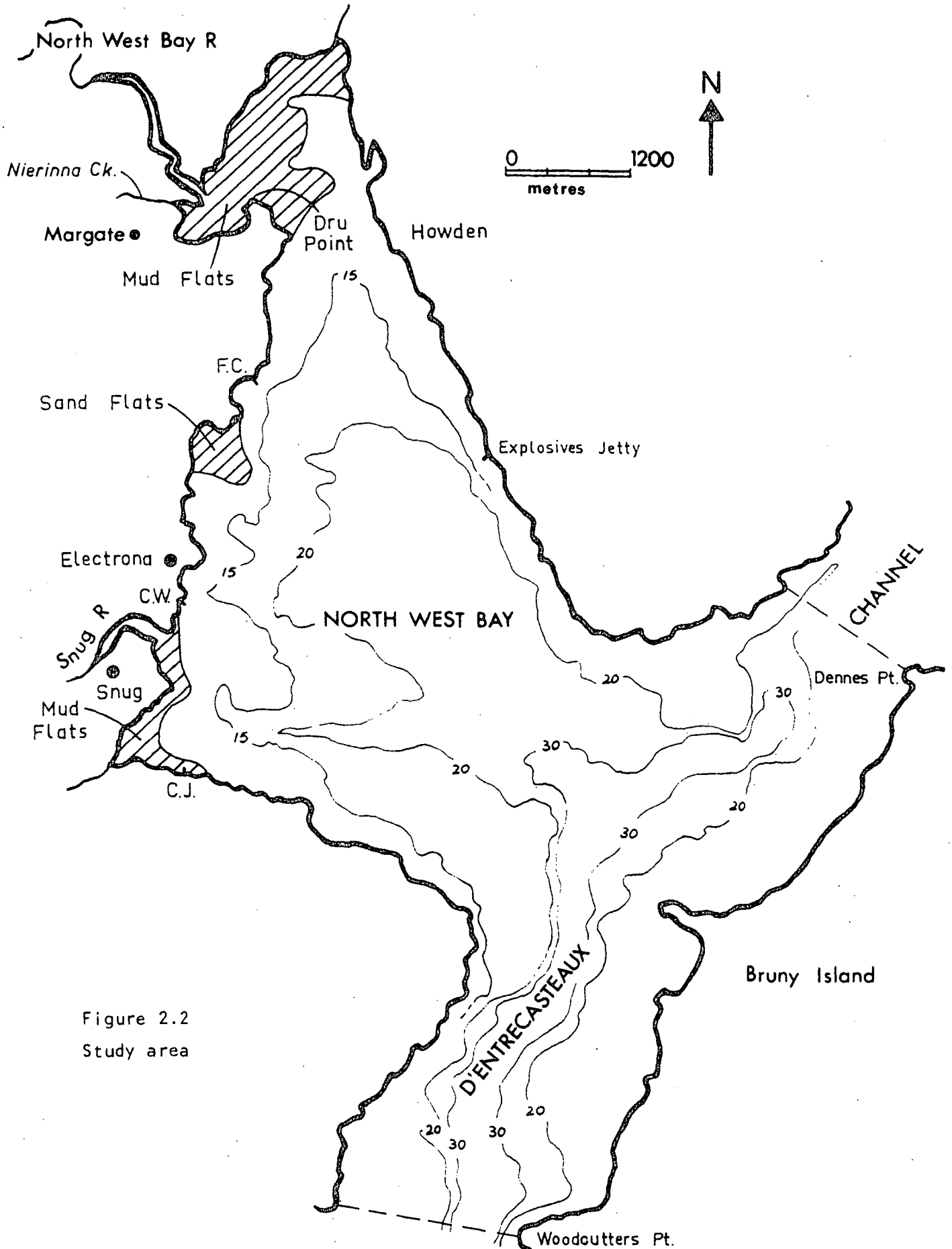


Figure 2.2
Study area

The bay affords an excellent natural harbour for small vessels such as fishing boats and various pleasure craft. It has a small surface area (about nineteen square kilometres) and, being isolated from oceanic swells by Bruny Island, offers considerable potential for boating and fishing. The entrance to the bay (about three kilometres wide) does not link directly to the sea but opens out into the northernmost part of the D'Entrecasteaux Channel. For 'sea going' craft this offers a link to Storm Bay (the mouth of the Derwent estuary) in the north and the Tasman Sea to the south.

No major rivers drain into the bay. Thus, excepting periods of flood and a small estuarine section in the north-west corner, the bay can be expected to be euhaline (marine) throughout the year¹. Virtually no information exists on the ecology of the bay as a whole. However, there have been some intensive studies carried out in the small estuarine region which is an ongoing area of study for post-graduate students of the Zoology Department of the University of Tasmania. The most important of these is a study by Walker¹ in which he investigated the faunal and floral structure of the estuary. Although his findings are too numerous to detail, Walker² concluded that a number of species could be threatened by development in the vicinity of this estuarine environment.

At the request of the Kingborough Council, a study group from the Tasmanian College of Advanced Education³ prepared a report on this area. Using supporting statements by Walker² and Guiler⁴ they stressed its ecological importance, with particular reference to its role as a habitat, in the food chain, and as a breeding ground for many marine species. In response the Kingborough Council⁵ has proposed that the area be included in the National Estate. Hopefully information on the circulation within the bay will also add to the understanding of this small sensitive estuarine region.

2.2 Climate

While no permanent meteorological station exists in the vicinity of North West Bay, a general picture of the climatology of the area can be inferred from data gathered at Hobart by the Bureau of Meteorology.

The climate of the region can be broadly classified as maritime temperate⁶ with rainfall being fairly evenly distributed throughout the year. Table 2.1 gives some monthly statistics on temperature, rainfall and barometric pressure for Hobart, from which some insight into the seasonal variations in climate can be gained. Figure 2.3 shows the (annual) distribution of rainfall throughout the area.

Since wind was one of the parameters investigated during this study, it is unfortunate that no permanent wind station exists at North West Bay. However, the Bureau of Meteorology operated a station at Kingston, between 1965 and 1973, from which broad wind patterns can probably be inferred. From wind roses, presented in Figures 2.4 and 2.5, it can be seen that north-westerly and westerly winds tend to predominate throughout the year, except for summer afternoons when winds are mainly south-east due to the influence of the sea-breeze. These winds occasionally exceed speeds of 60 km h^{-1} , while sea-breezes rarely exceed 16 km h^{-1} . It is worth noting that a considerable part of the field investigations for this study were carried out during the calmest months of the year, that is, May, June and July.

2.3 Rivers and Catchment

The total watershed for the bay is fairly small covering an area of only about 260 square kilometres (see Figure 2.6). Table 2.2 gives a comparison of the catchment areas for the various rivers and streams that drain into the bay.

Table 2.1
CLIMATOLOGICAL STATISTICS FOR HOBART⁶

Month	Mean Temperature °C (93 years)		Mean Rainfall (94 years)		Mean Barometric Pressure (mb) (91 years)
	Maximum	Minimum	Total Fall (mm)	No of Rain Days	
January	21.4	11.6	49	11	1010.6
February	21.5	11.8	41	10	1012.9
March	20.0	10.6	47	11	1014.3
April	17.1	8.7	55	12	1015.5
May	14.2	6.7	49	14	1015.4
June	11.8	5.1	59	14	1015.3
July	11.4	4.4	54	15	1014.0
August	12.8	5.0	51	16	1012.8
September	14.9	6.2	52	15	1011.5
October	16.7	7.5	64	16	1010.3
November	18.5	9.0	56	14	1009.8
December	20.2	10.5	57	13	1009.3
ANNUAL	16.7	8.1	634	161	1012.6

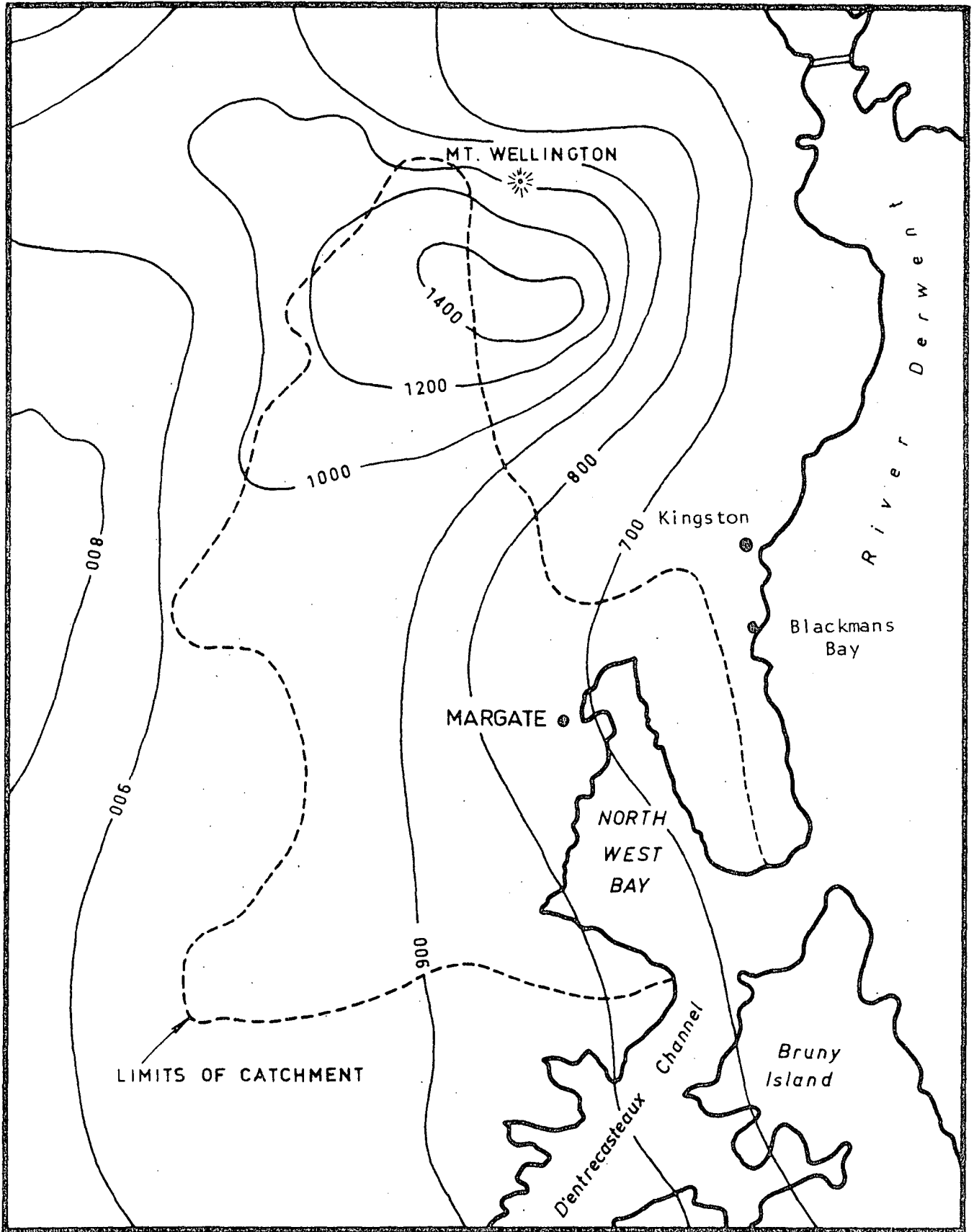
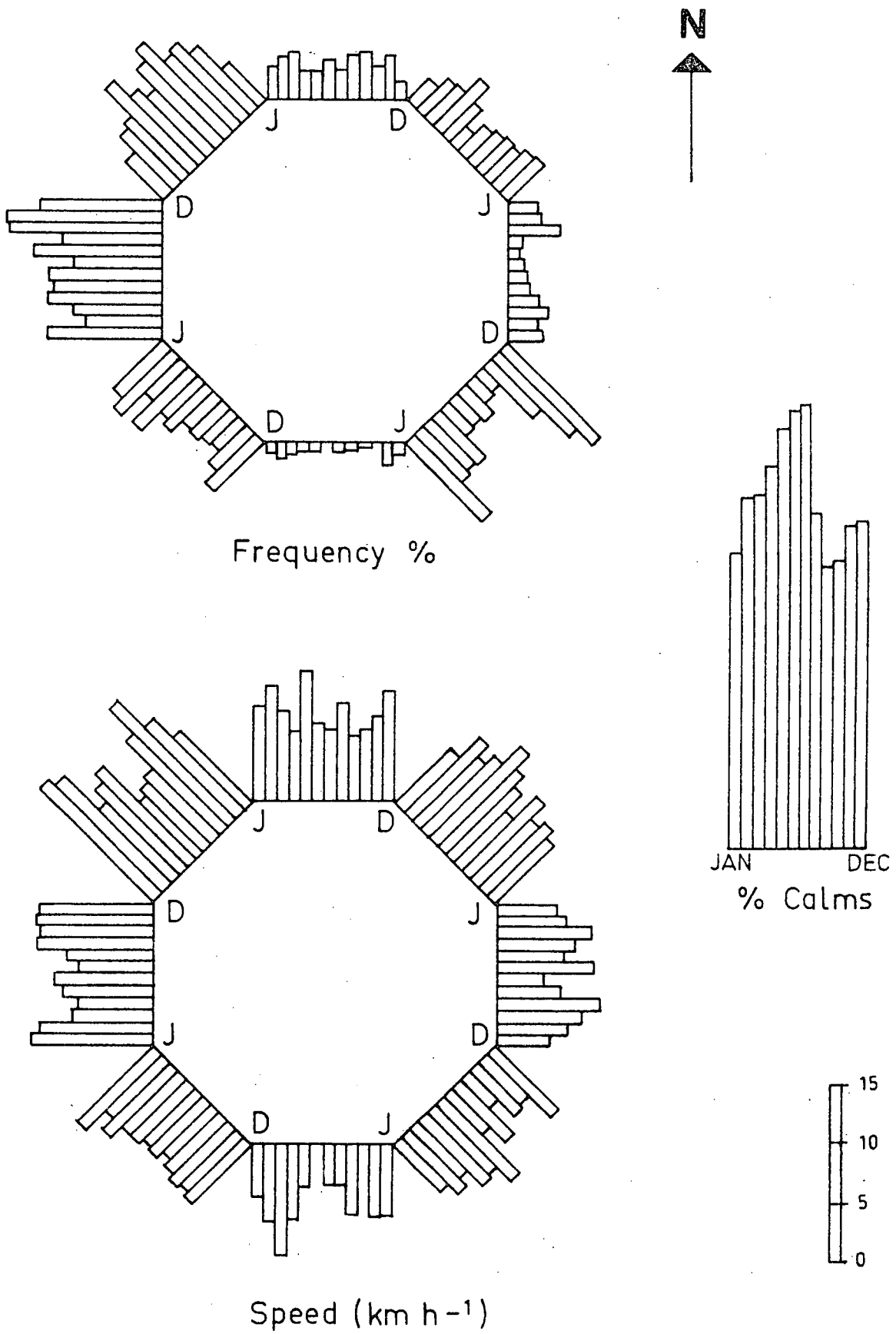


Figure 2.3 Annual rainfall isohyets⁶



0900 hrs.

Figure 2.4 Wind roses (Kingston 1965-73)

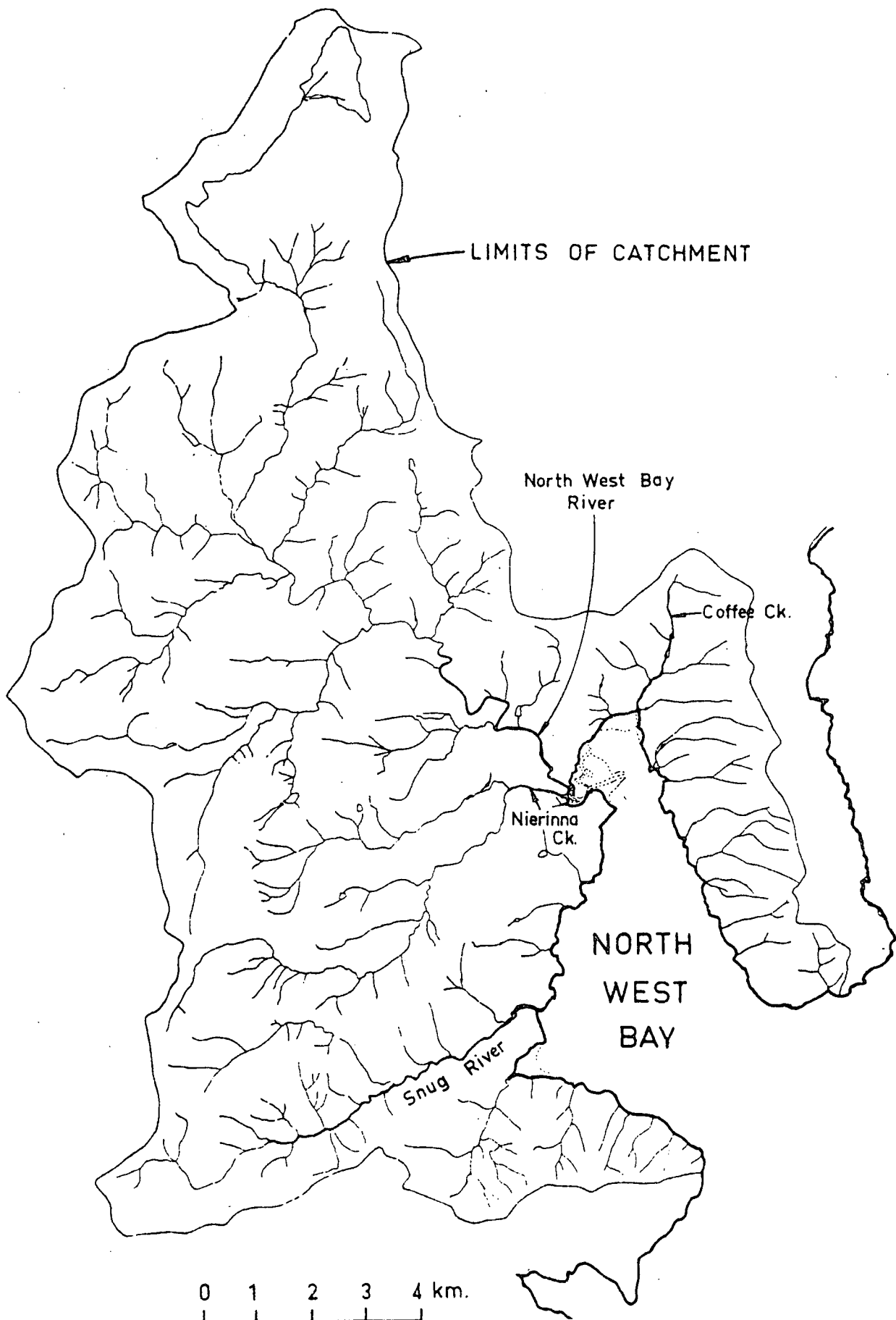


Figure 2.6 North West Bay Watershed

Table 2.2
STREAM CATCHMENTS IN THE NORTH WEST BAY WATERSHED⁷

STREAM NAME	CATCHMENT AREA (km ²)	% of TOTAL
Coffee Creek	7.5	2.9
Snug River	23.5	9.1
Nierinna Creek	27.2	10.5
North West Bay River	178.0	68.7
Other	22.8	8.8
TOTAL	259.0	100.0

It can be seen from Table 2.2 that the bulk of the freshwater input to the bay will be derived from the catchment of the North West Bay River, which, together with Nierinna Creek and Coffee Creek, drains into the mudflats in the north-western corner of the bay. Thus this is undoubtedly the most sensitive region of the bay with regard to any disturbance of the natural hydrological regime in the watershed.

It can be seen by referring to Appendix A that, at present, the catchment is still relatively undeveloped, with 66% being under natural vegetation, but strong pressure for urban and industrial development can be anticipated.

Hydrological information for the watershed is available from two stations monitored by the Rivers and Water Supply Commission, one on the North West Bay River and the other on the Snug River. With the aid of this information Badcock⁷ has estimated the relationship between annual precipitation and annual runoff for the various river basins in the watershed. His estimates for the annual freshwater discharge into the bay are shown in Table 2.3.

Table 2.3
ESTIMATED TOTAL ANNUAL FRESHWATER DISCHARGE
INTO NORTH WEST BAY⁷

STREAM	VOLUME OF FRESHWATER DISCHARGE ($m^3 \times 10^6$)	% of TOTAL
1. Howden Tinderbox Peninsula Area	1.36	1.2
2. Coffee Creek	1.20	1.0
3. Margate Rivulet and Nierinna Creek	7.06	6.0
4. Snug Point Area	2.18	1.8
5. (a) Snug River	3.61	3.1
(b) Melville Creek	9.42	8.0
6. North West Bay River and Tributaries	92.97	78.9
TOTAL DISCHARGE	117.8	100.0

Badcock⁷ has also drawn some conclusions on the response characteristics of the Snug River and North West Bay Rivers. His analysis focussed on the Snug River, as its flow gauge is more reliable, and indicated that the characteristics of the North West Bay River are probably similar, although he could not demonstrate this conclusively. He indicates that flood flows are at least two orders of magnitude greater than annual average flows; that the 'memory' of the system is no more than five to six days after periods of rainfall (although this is lengthened during periods of snowfall); and that the concentration time is in the order of an hour.

Both the North West Bay River and Nierinna Creek drain onto the mudflats in the north-western corner of the bay, their mouths being separated by only 100 metres. It can be seen, by referring to Table 2.3, that these two streams account for 85% of the

freshwater input into the bay. Hence an estuarine region would be anticipated in the vicinity of the mudflats. However, except for periods of flood, most of the bay would in fact be expected to be euhaline (marine) since the total freshwater input ($118 \times 10^6 \text{ m}^3/\text{yr}$) is relatively small. It will be seen, in Section 2.5, that this conclusion is supported by observations of salinity by Walker¹ and Thompson⁸.

2.4 Hydrography, Tides and Flushing

The most recent depth soundings available for the bay were carried out by the Australian Navy in 1966. It can be seen from Figure 2.2 that most of the bay is fairly deep (in excess of fifteen metres) having formed as a system of drowned river valleys. The eastern shore drops off rapidly into a deep channel which is probably one of the drowned Tertiary valleys proposed by Moore⁹. In contrast, parts of the western shore are fairly shallow with numerous areas of sand and mudflats occurring, these being most extensive in the north-western corner of the bay.

A brief investigation¹⁰ confirmed that tides in the bay are semi-diurnal and correspond closely with tide tables¹¹ that have been prepared for the Port of Hobart. Intertidal heights are fairly small with a maximum intertidal range of about one metre and a mean range in the order of half a metre. Compared to a total low-water volume of approximately 277×10^6 cubic metres, the tidal prism of the bay is small. For a 0.5 metre tide, the volume contained in the prism is about 9.52×10^6 cubic metres or 3.4 percent of the total low-water volume of the bay. Thus on this basis it could be anticipated that the magnitudes of tidal currents would be small and the rate of exchange of the bay with adjacent waters, would be low.

If it can be assumed that tide is the dominant exchange mechanism for the bay, and that complete mixing occurs on each tidal cycle, the proportion of the bay water removed on each cycle can be estimated from the simple tidal prism.

This is given by

$$r = \frac{P}{V + P}$$

r = proportion of bay water exchanged (ie. exchange ratio)

V = total low-water volume of the bay

P = volume contained in the tidal prism.

Thus for a mean tide of 0.5 metres this gives an exchange ratio of 1:30 per tidal cycle, (1:15 per day).

The tidal prism approach can also be applied to estimate mean velocities of tidal currents. This has been done for a number of sections across the bay, assuming a 0.5 metre tide and a tidal period of twelve hours, and the estimated velocities are presented in Figure 2.7. On this basis it might be expected that tidal currents would rarely exceed 2 cm sec^{-1} .

However, if the underlying assumptions with regard to exchange mechanisms and mixing are not met, these calculations may not be valid. These aspects have been considered in this study and are discussed further in Section 4.

2.5 Hydrological Aspects

Some background information on the variations in temperature and salinity, within the bay, is available from observations at monthly intervals by Walker¹ (May 1973-August 1975) and Thompson⁸ (Sept 1975-March 1977). The location of their sampling stations is shown in Figure 2.8, while their data is presented graphically in Figures 2.9-2.11. For the purposes of comparison, the monthly rainfall at Margate, over the period of these observations is presented in Figure 2.12.

This data indicates that, apart from a small estuarine region near the mouths of the North West Bay River and Nierinna Creek, the bay is generally euhaline throughout the year. However, due to riverine dilution salinities tend to fluctuate. Although no distinct seasonal trend is apparent, at times they approach those of coastal waters (see Figure 2.15) exceeding 34.8‰, while occasionally, following periods of heavy rainfall, they may fall below 30‰.

As would be expected, water temperatures show a strong seasonal trend, with winter minima about July and summer maxima around February, about a month earlier than for coastal waters (see Figure 2.15). Thompson's data indicates that temperatures range from less than 9°C in winter, up to 19°C in summer, although these extremes appear to be slightly moderated with depth and towards the head of the bay. Walker's data show a greater range of fluctuation, although his measurements are confined to near surface readings and are undoubtedly influenced by waters derived from the shallow regions around the mudflats.

A particularly interesting feature of Thompson's data is that the temporal variations in salinity (in the bay) often appear to be greater than the salinity gradients. This tends to suggest that a sampling period of one month is 'coarse', with respect to the rate of water exchanges occurring, and that fairly complete mixing occurs in a much shorter time period. However, it should be noted that Thompson's measurements are taken at near shore locations and may display localised effects.

While an estuarine influence from the Derwent River would be expected, some earlier information gathered by Taw^{13,14} also suggests the possibility of an influence from the Huon. Taw monitored salinity (see Figures 2.13 and 2.14) at monthly intervals between August 1971 and July 1972 at two stations in Storm Bay and at one station in the D'Entrecasteaux Channel (see Figure 2.8). This data (see Figure 2.13), August-November 1971) suggests that at times there may be positive salinity gradient (towards Storm Bay) in the D'Entrecasteaux Channel, which could be attributable to a freshwater input from the Huon River. It was one of the aims of this investigation to gather more information on some of these effects.

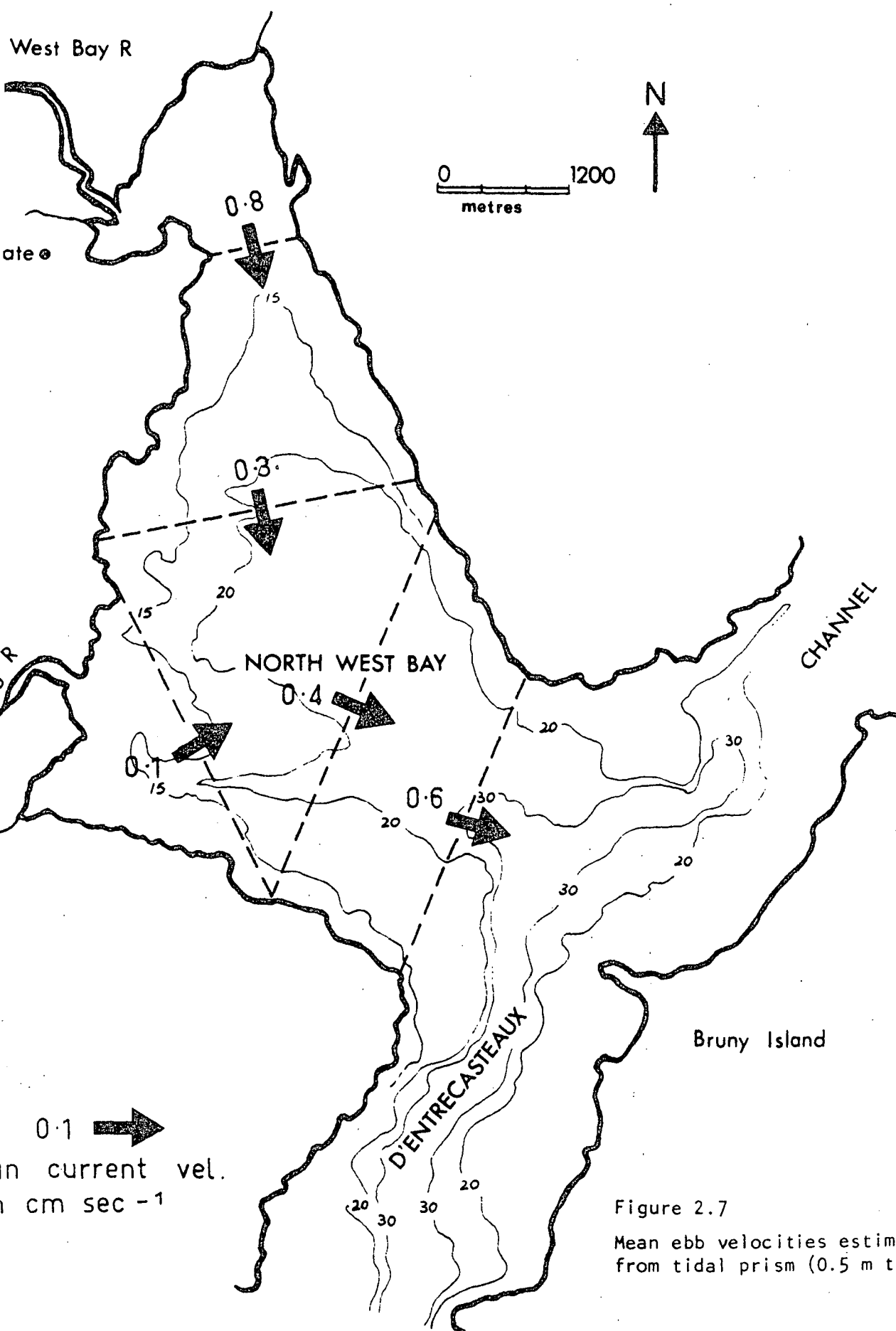
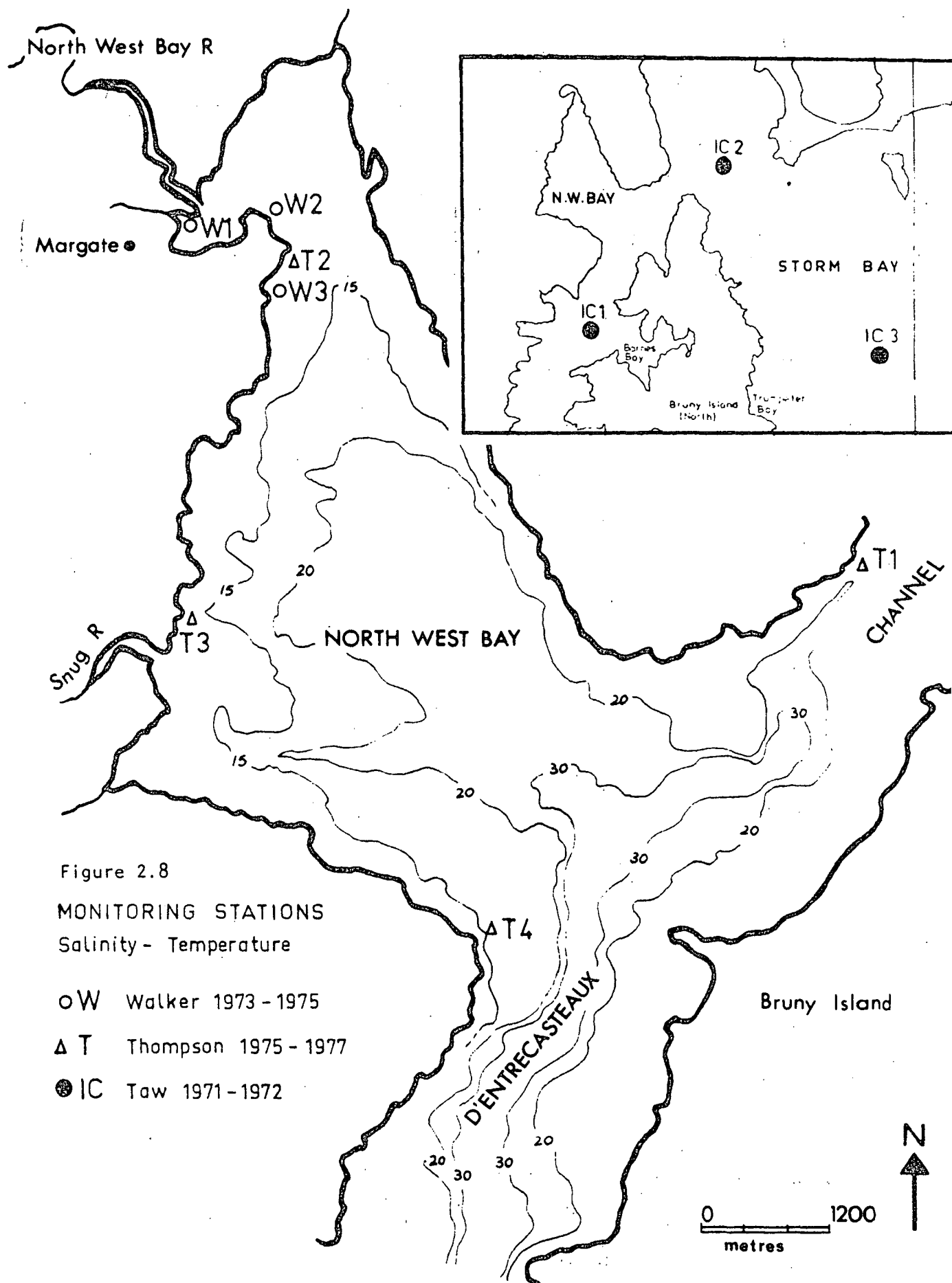


Figure 2.7

Mean ebb velocities estimated
from tidal prism (0.5 m tide)



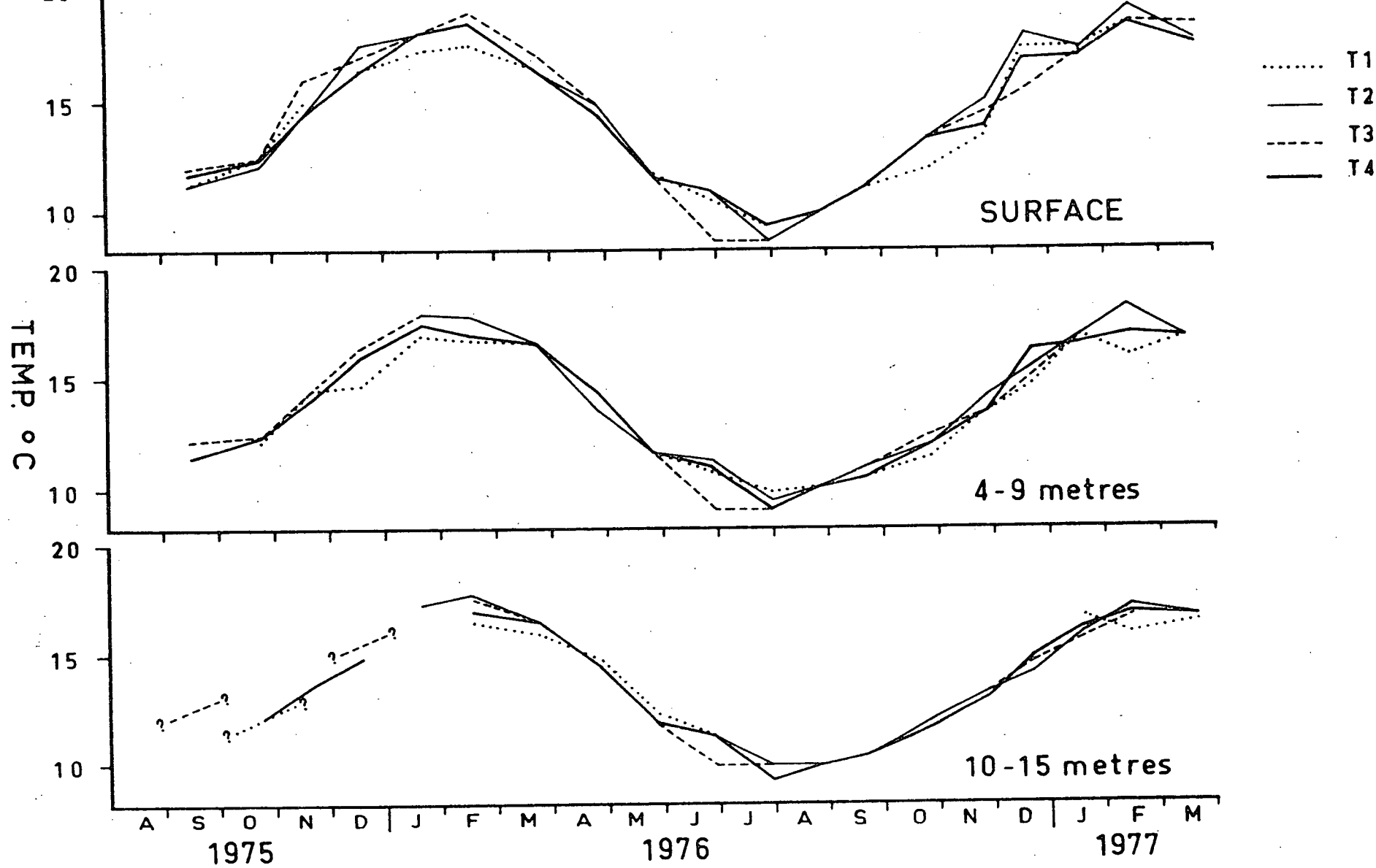


Figure 2.9 Temperature measurements - Thompson⁸

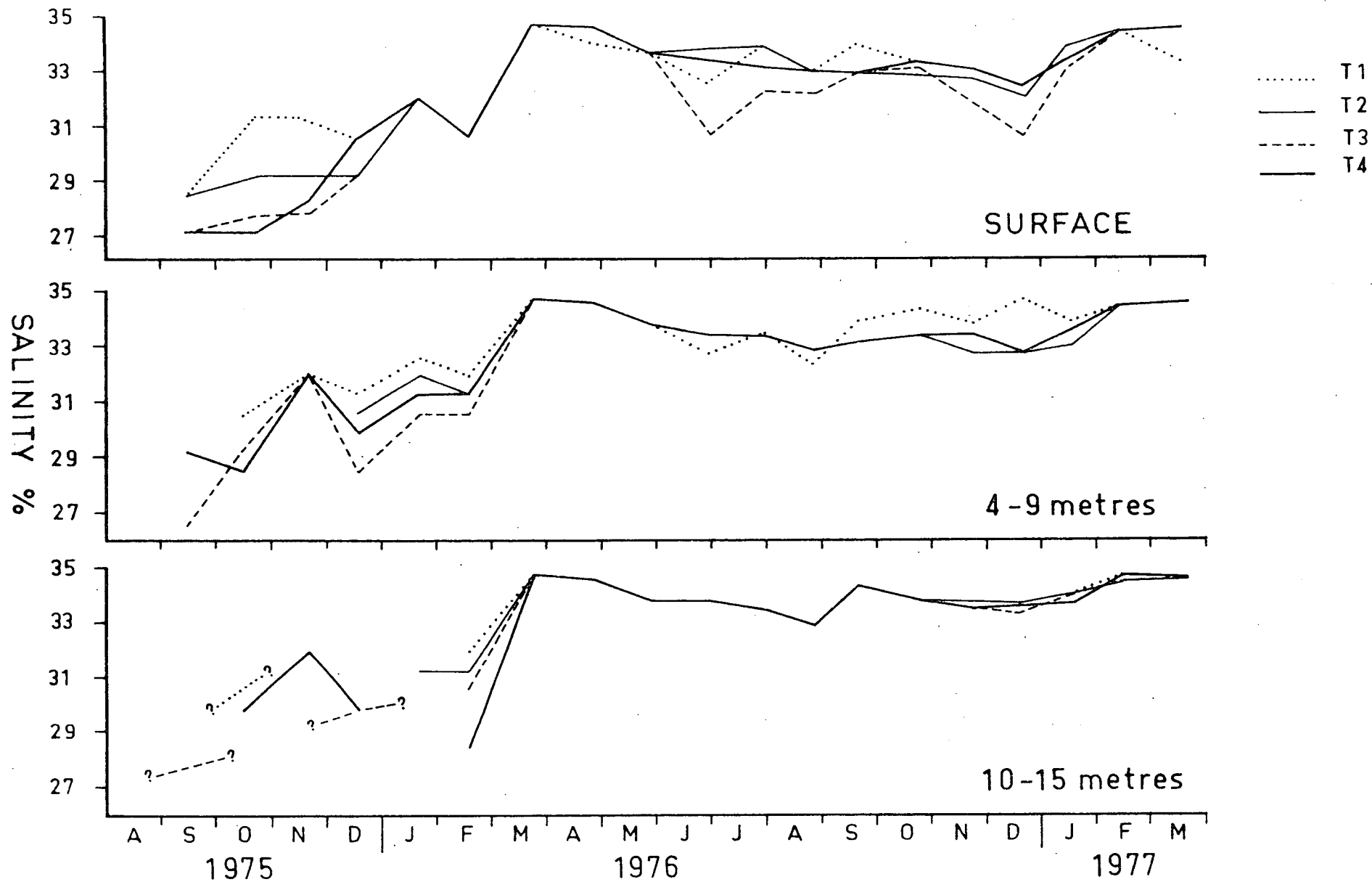


Figure 2.10 Salinity measurements - Thompson⁸

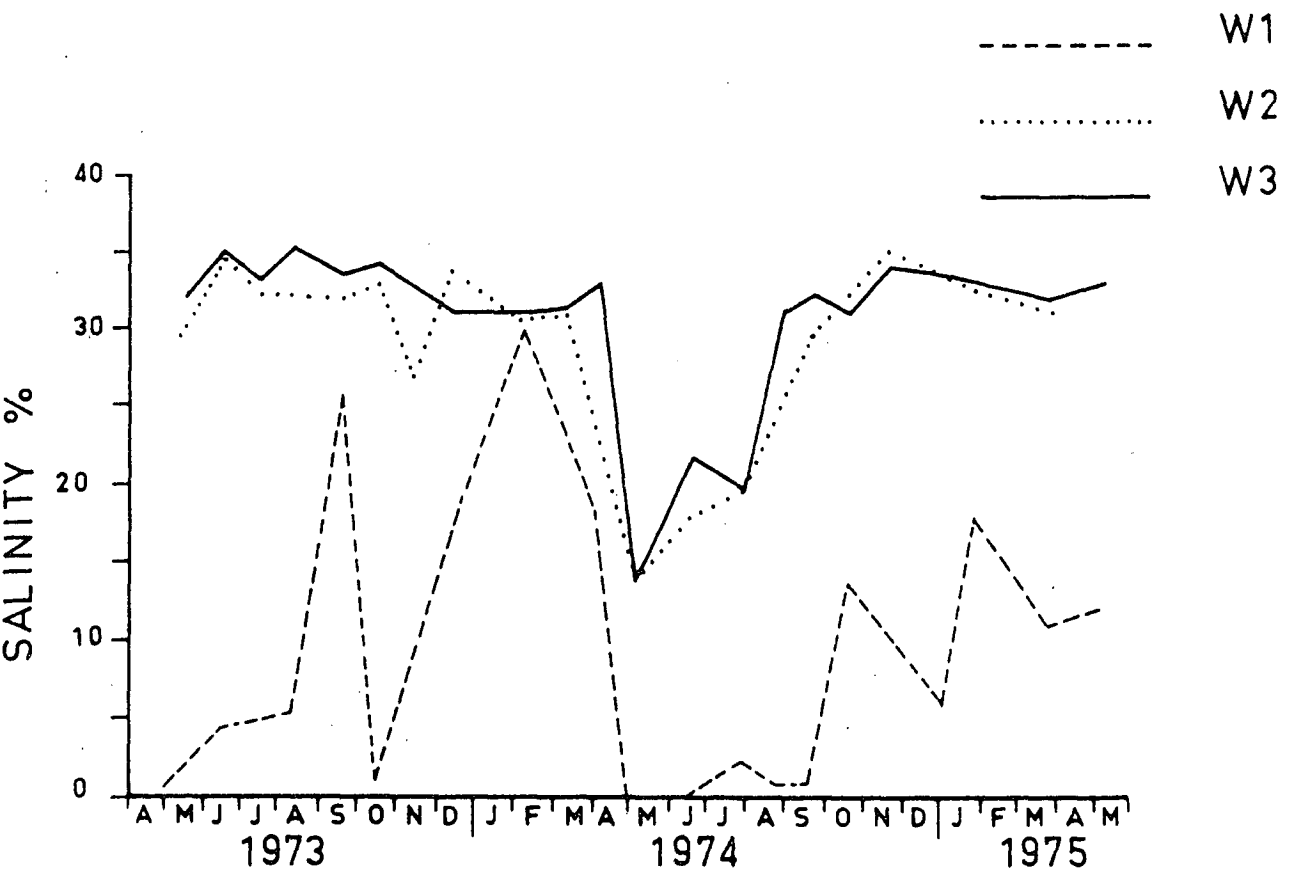
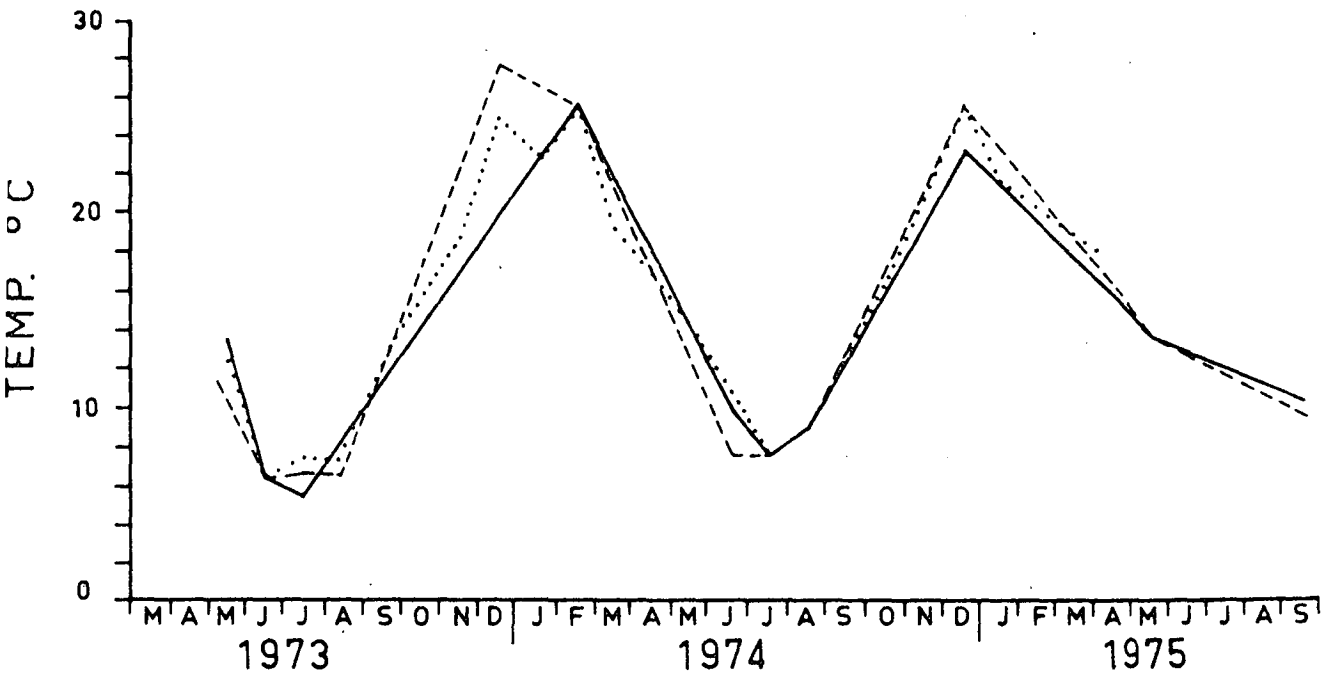


Figure 2.11

Salinity-temperature measurements
- Walker¹

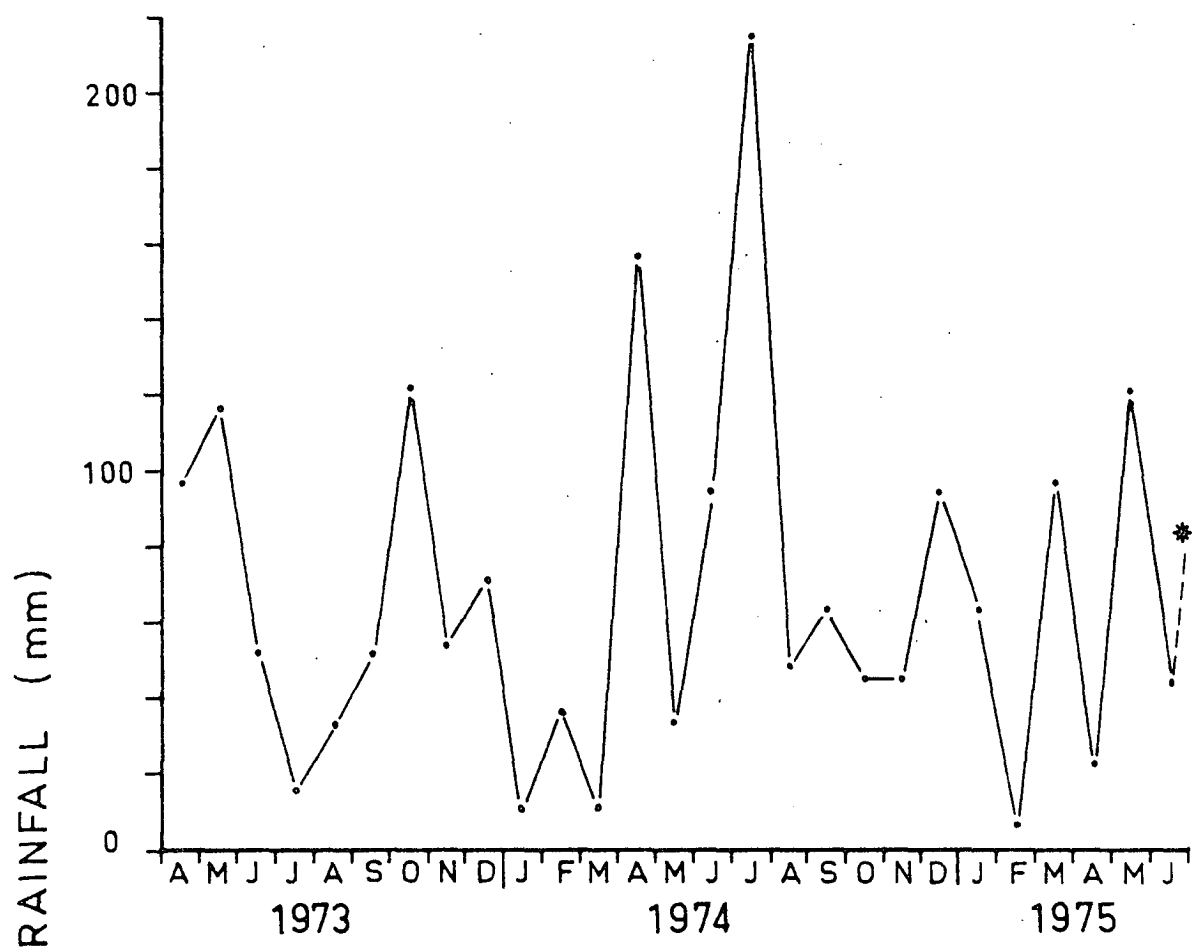


Figure 2.12

Monthly rainfall - Margate

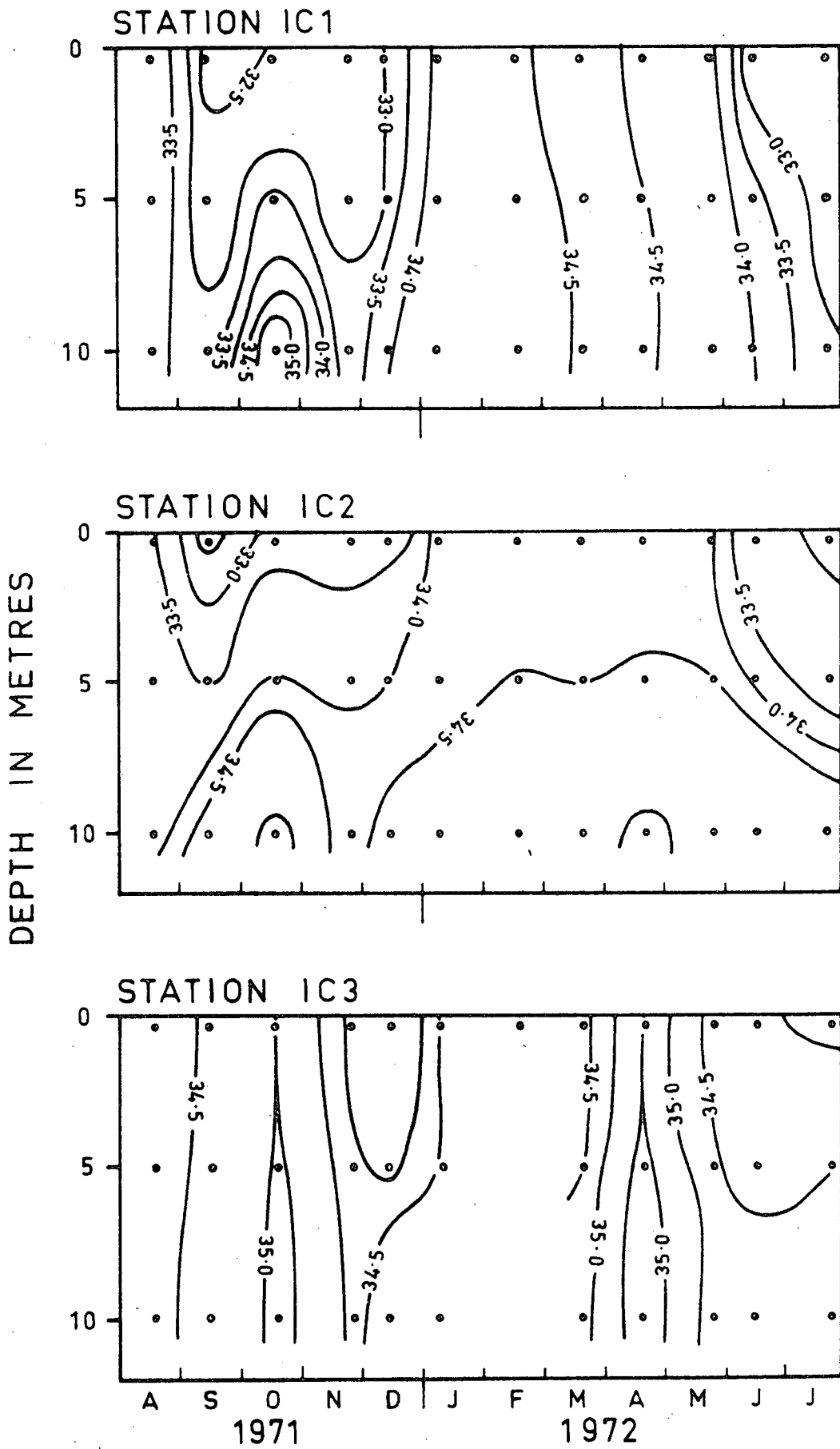


Figure 2.13

Salinity measurements
- Taw¹⁴

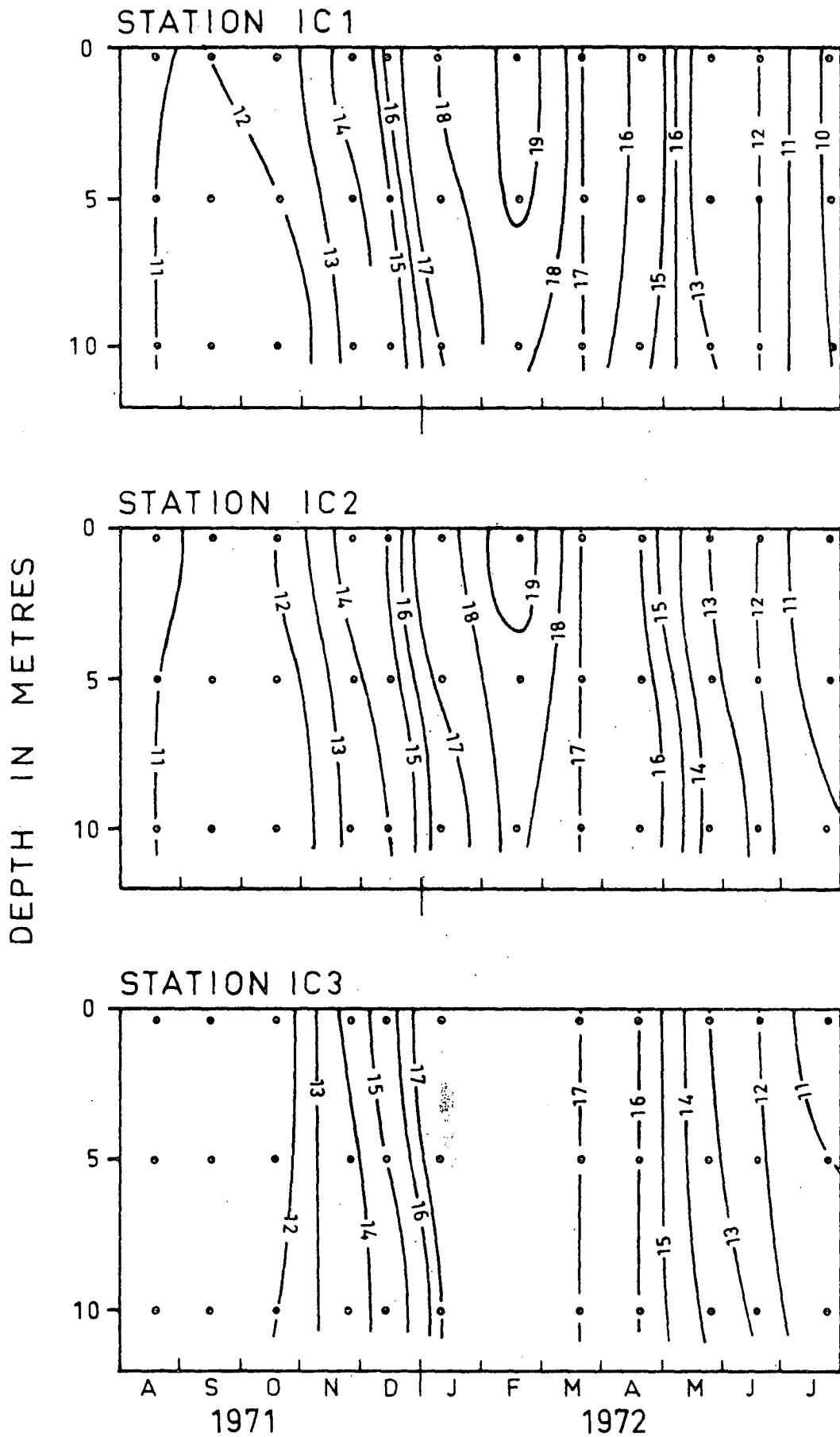


Figure 2.14

Temperature measurements
- Taw¹⁴

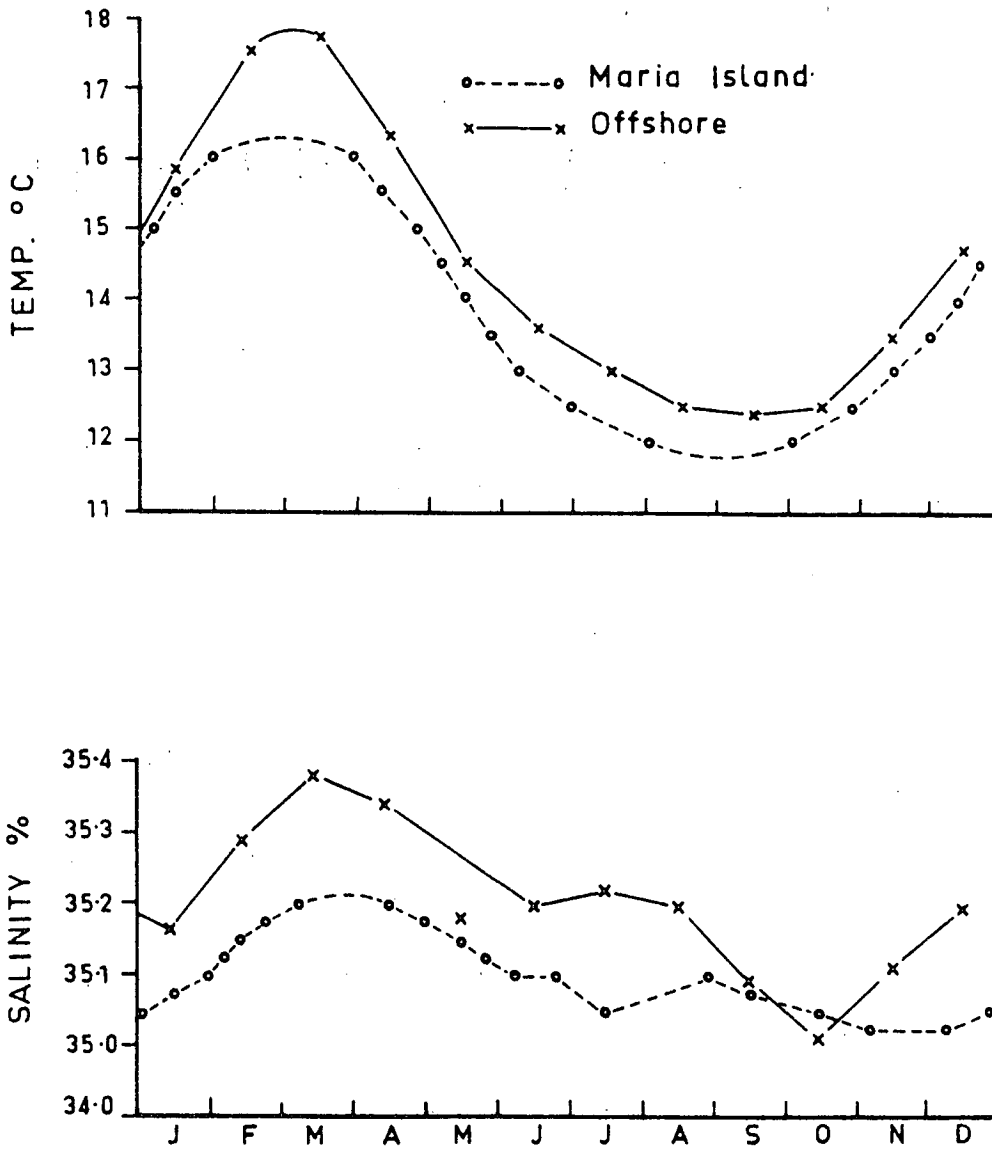


Figure 2.15 Mean annual surface temperature and salinity, Maria Is. (1945-72) and same 48 km offshore (1966-73) - Rochford¹⁵

2.6 Summary

- . North West Bay is a sheltered embayment, isolated from direct oceanic influences, which offers considerable potential for water based activities.
- . Background information on the ecology, hydrology and hydrodynamics of the bay is sparse.
- . The climate of the region can be broadly classified as maritime temperate with rainfall being evenly distributed throughout the year.
- . Because of the small watershed, freshwater runoff into the bay is low. Thus most of the bay can be expected to be marine throughout the year.
- . Preliminary calculations based on the tidal prism indicate that tidal currents and rate of flushing for the bay could be low.
- . Available background data tends to confirm that the bay is generally marine, with small fluctuations in salinity occurring. These fluctuations may in part be due to external estuarine influences, (Derwent and Huon estuaries).
- . Water temperatures show a strong seasonal trend with extremes occurring about a month earlier than coastal waters.

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**methodological considerations
and techniques**

3. METHODOLOGICAL CONSIDERATIONS AND TECHNIQUES

It is essential that research methodology and available techniques be tested and evaluated prior to any detailed research program being implemented in either North West Bay or other estuarine and marine areas of Southern Tasmania.

This section presents a range of techniques and equipment used in estuarine and coastal studies, and discusses the techniques employed in this study by examining the design, limitations and problems encountered with the equipment used. As such, this section fulfils the requirement of the sixth objective given in Section 1.4.

3.1 Background (Methods and Techniques)

The basic methodology employed in this study evolved from an evaluation of the material given in a selection of literature relevant to estuarine and oceanographic studies.

This section briefly considers a range of techniques available and reflects upon their applicability to this study. A more comprehensive and varied treatment of each technique can be obtained from the references.

3.1.1 Current metering

The use of current meters provides a Eulerian measurement of the velocity and direction of water flow past a fixed point at a given time, with the information obtained being the aggregated sum of the various mechanisms such as wind stress, density gradients, tidal currents, etc.

Various types of current meters are available^{1,2,3} with the majority of these types being of rotor⁴⁻⁷, solid state^{4,8-11}, drag vane¹²⁻¹⁵ or electromagnetic and free falling probe¹⁶⁻²³ types.

An Alekseev $\delta\pi$ B-2 current meter utilising a savonius rotor was used for current metering in this study. This equipment has the advantage of having a clockwork mechanism and speed range which will accommodate estuarine conditions and a paper tape for direct read out. The equipment and its operation are given in Section 3.2.1.

3.1.2 Drogue tracking

The use of drogues is a Lagrangian technique which enables the determination of a flow path for the period of observation of the drogue. Drogues can be suspended at various depths by the use of surface flotation and their position tracked by the use of a sextant and known shore reference points, or by the use of land based survey stations with theodolite or radar tracking techniques.

Drogues perform a self integrating function which will eliminate small scale turbulence effects. Their use allows a mean velocity to be measured accurately if the drogues are tracked for a reasonable amount of time. The disadvantages of drogues include the need to track the drogue for a long period of time, and the problems of undesired forces deviating the drogue from its true path. Two different drogue designs were constructed for use in this study as outlined in Section 3.2.2.

3.1.3 Marker dyes

Dye tracing is a technique that gives broad scale dispersion and circulation information for the water body. This technique involves the release of dyes (rhodamine and fluorescein) at required locations and depths so that the dye may be tracked by aerial photography^{30,31} or by sampling the fluorescein content of the water body over a systematic grid network^{25,29}. The cost, manpower and equipment requirements of this technique made it prohibitive for use in this study, therefore it was not used.

3.1.4 Salinity-temperature measurements

The knowledge of the salinity-temperature structure of estuaries and coastal waters is a well established technique for determining the resultant density and diffusion currents 40-59.

A time series of the salinity-temperature structure of the particular water body is essential in providing information with respect to the gross exchange and flushing properties of the body where inputs of fresh water from land drainage can be used as a natural tracer.

The principles of operation of salinity-temperature meters is well documented³²⁻³⁹, and many commercially made, portable meters are available for use in oceanographic investigations.

Extensive use was made of salinity-temperature measurements in this study as given in Section 3.2.3.

3.1.5 Tidal measurements

The use of tide gauges is important in determining the nature and degree of the meteorological and astronomical driving mechanisms within the given water body⁶⁶⁻⁸⁰. The use of gauges with suitable frequency response enables other phenomena such as seiches, storm surges, tsunamis, and surface wave and swell structure to be determined from the analysis of tide gauge records.

The majority of tide gauges are of tide-well types⁶³⁻⁶⁵ or types utilising pressure transducers located beneath the water surface^{4,60-62}. A simple tide stick and a continuous tide level recorder were constructed for use in this study and the tidal monitoring program is outlined in Section 3.2.4.

3.1.6 Visual observations

Visual observations of the surface of the water body can provide information with respect to circulation patterns and phenomena occurring in the water body. One such phenomena is the observation of periodic surface slicks

related to internal waves within the water body^{28,66,74,81,82}. Other observations include wind slicks²⁸ and shear lines between water bodies of differing densities and velocity characteristics. The tracking of discoloured fresh water runoff into a water body can often provide useful information. Visual observations in North West Bay provided some information with respect to general circulation patterns and other phenomena occurring in the bay.

3.1.7 Physical models

The use of physical models for studies of circulation in estuaries and coastal waters requires a great deal of expertise in recreating the actual physical area to scale, and to represent the driving mechanisms of that water body in the correct manner^{3,83-91}. The cost, time and data required to construct and calibrate such models places severe restrictions on their use in circulation studies and it is doubtful if such models will provide more accurate predictions and knowledge of the circulation than would mathematical models or detailed field investigations.

3.1.8 Mathematical models

A wide variety of mathematical models have been used to simulate and predict circulation and pollution transport within estuaries and coastal areas⁹²⁻⁹⁵. In particular, the use of two-dimensional hydrodynamic mathematical models has increased dramatically in recent years throughout the United States of America and Europe⁹⁶⁻¹⁰⁵. These types of models have been used recently in Australian coastal waters such as Port Phillip Bay¹⁰⁶, Westernport Bay¹⁰⁷⁻¹¹⁰ and Spencer and St. Vincent gulfs¹¹¹⁻¹¹³, with varying degrees of success.

The seventh objective of this study was to make a preliminary assessment of the use of such models in the study area in light of the field data that has been obtained. This assessment is included in the conclusions, Section 5.

3.2 The Study (Methods and Techniques)

The type of equipment that was either directly available or could be constructed imposed constraints on the range of techniques that could be utilised.

This section of the report details the characteristics and performance of the equipment and evaluates the techniques employed, their limitations, and some of the problems encountered.

3.2.1 Current metering

a. *Aims-expectations-evaluation*

The basic aims of the current metering program were to gain information on the nature of the driving mechanisms, particularly the astronomical and meteorological components, and to investigate local circulation patterns within the bay. This was to be done by carrying out a spectral analysis of the current meter data.

In the first respect the metering program was fairly successful. While some information on local circulation was obtained, because of problems in moving meter moorings, this was less than initially anticipated.

b. *Type-design-specifications-accuracy*

Two Russian built Alekseev бпБ-2 current meters (see Figure 3.1) were used for current metering over a period of five weeks. The meters have a clockwork paper tape recording mechanism (see Figure 3.2) recording current velocity in centimetres per second (cm/s) and direction in degrees. Various sampling rates from five minutes to one hour may be used and a sampling interval of 15 minutes was chosen for this study.

The current meters have a threshold velocity of 2.5 cm/s and can record currents up to 148 cm/s. The direction record error is given as a maximum of 12 degrees at the low threshold speed of 2.5 cm/s.

c. *Sampling depth-location-moorings-deployment*

Because of the low fresh water runoff into North West Bay there is generally no well defined stratification except at times of flood conditions. Consequently, it was decided to locate the current meters 10 metres below the water surface where the effects of surface wind stress and bottom bed shear would be minimal and the records would represent an average velocity value for the water column. At the beginning of field investigations it was envisaged that the meters be placed across the entrance of the bay, in positions 1 and 2 (see Figure 3.3), for three weeks. Then the meters would be relocated in positions 3 and 4 for the final two weeks so that a broader picture of the internal circulation of the bay would be obtained. A taut wire mooring system was used to suspend the current meters in a frame above the sea bed. A separate large marker buoy was used with a second small marker buoy attached to the top of the meter frame with a light-weight rope which made it easier for divers to locate the frame and meter when routine data recovery and mooring checks were made. Details of the mooring system and meter frame are given in Figures 3.4 and 3.5.

Initially the two meters were placed at positions 1 and 2 using a large tug and derrick which was provided by the Hobart Marine Board. At the chosen sampling rate the meter clock had to be rewound and the tapes replaced every fifteen days. This was done with a diver and small boat, and required lifting bags to support the weight of the meter (approximately 40 kg when submerged). The time taken was about half an hour in good weather. The method intended for moving the meters to positions 3 and 4 was to tow the moorings (by powered boat) after the meters had been removed from the frames. This operation was only partially successful.

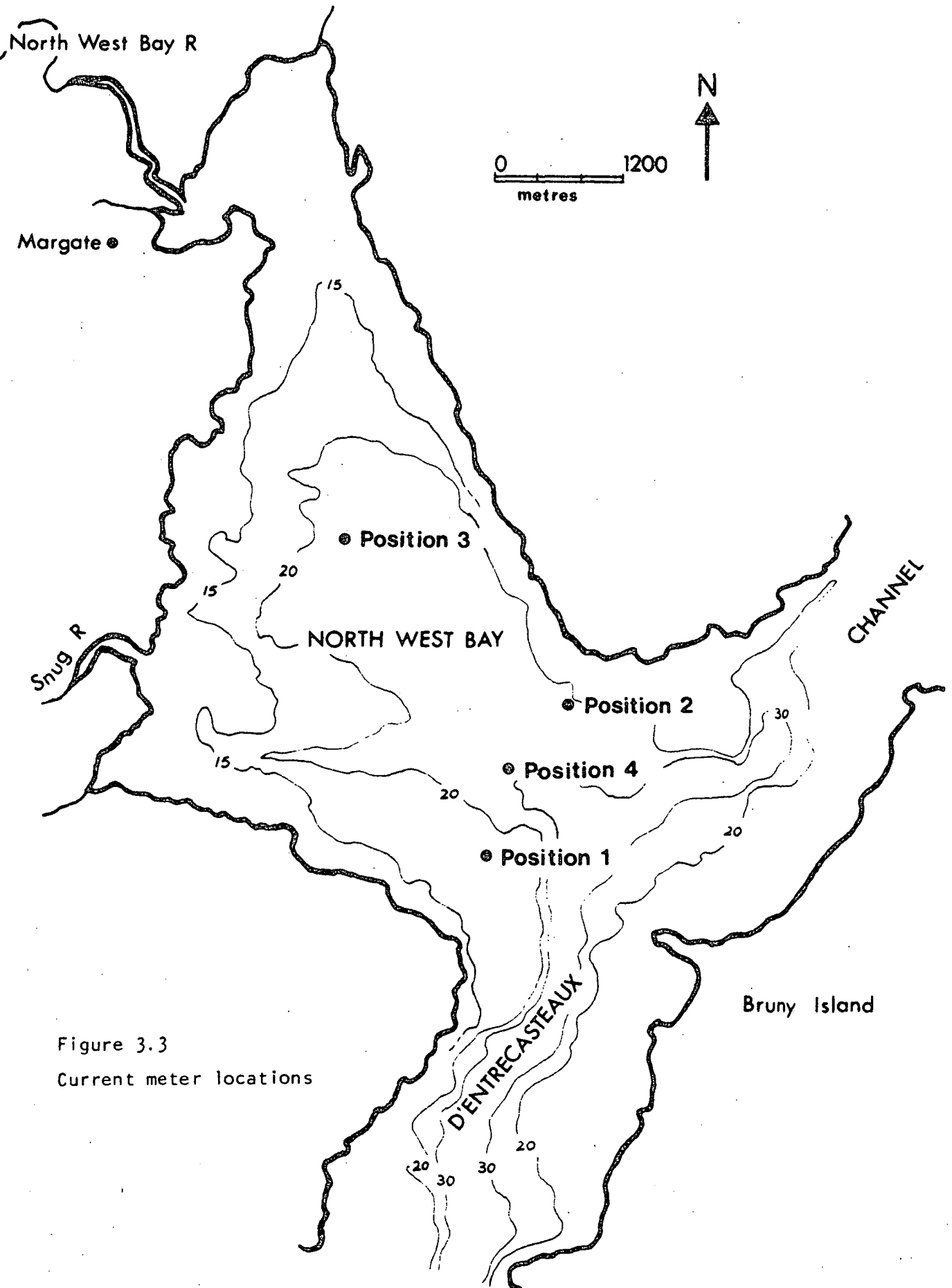


Figure 3.3
Current meter locations

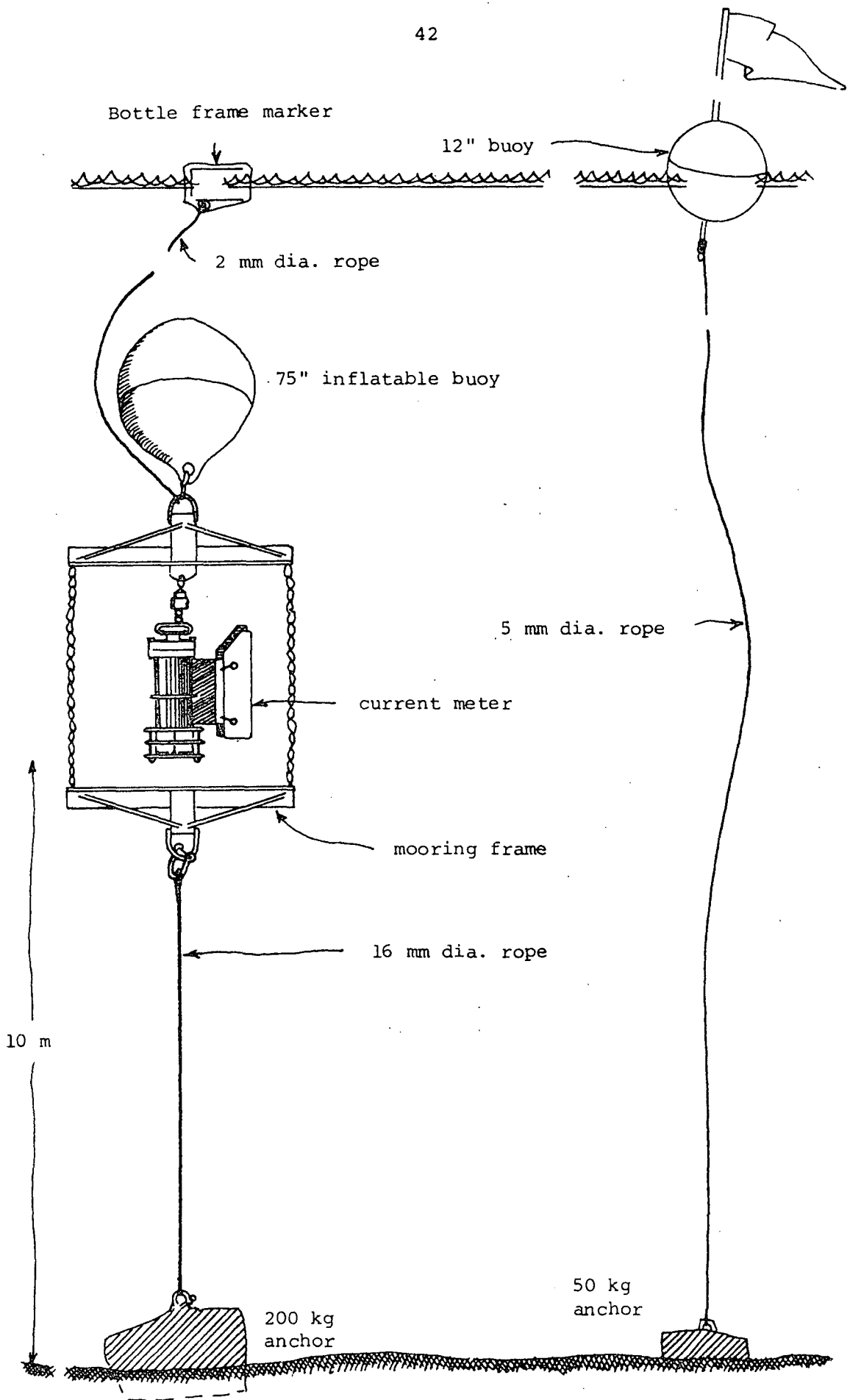


Figure 3.4

Current meter mooring system

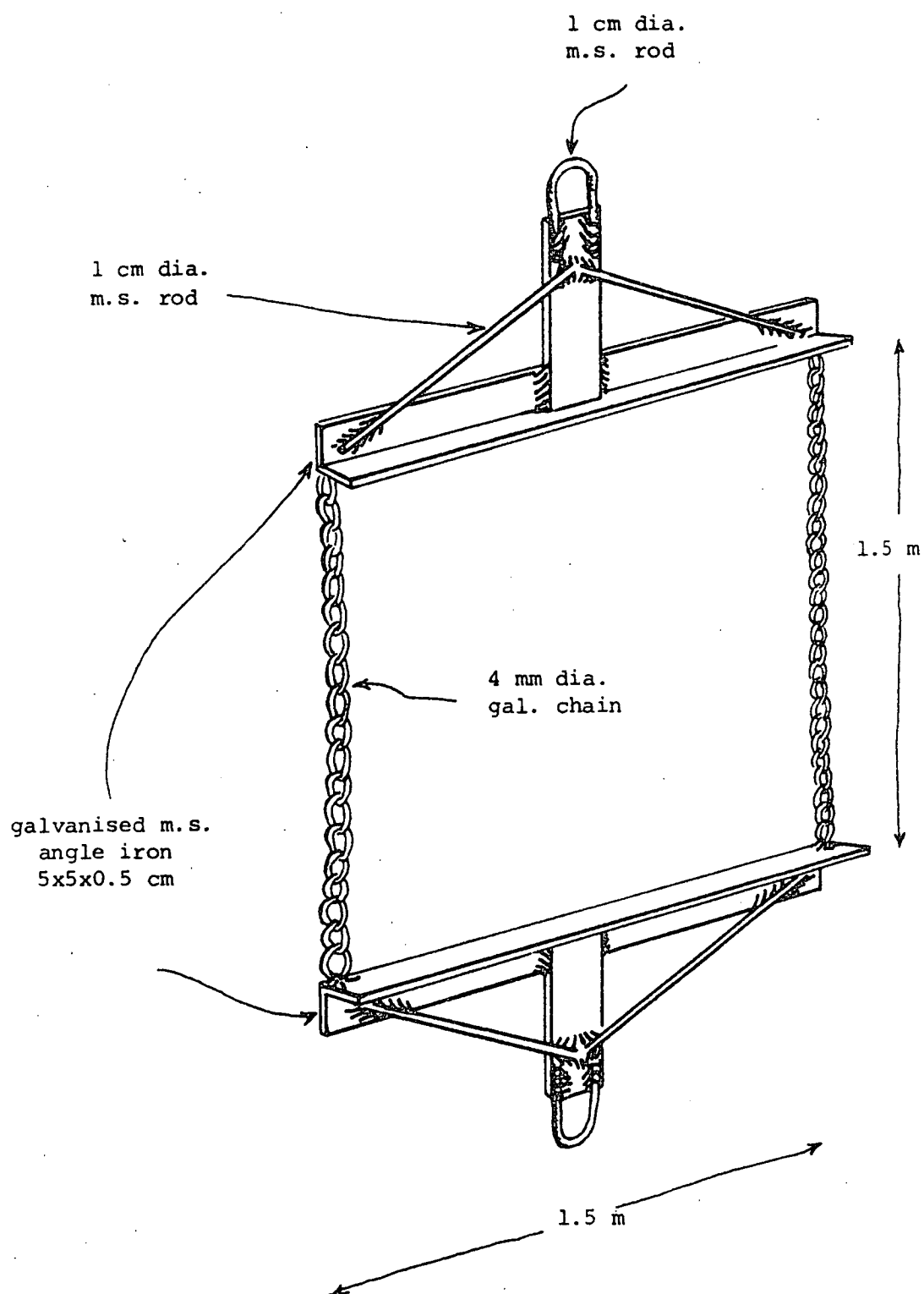


Figure 3.5 Current meter mooring frame

d. *Limitations-problems-recommendations*

Two major problems occurred during the study period. The first was realised when the meters were inspected fifteen days after the initial deployment. The meter mooring in position 1 had settled to the sea bed due to the compression of the flotation buoy. On inspection of the current meter record, it was obvious that the meter had settled only two days before the inspection. This meter was removed and used for profiling until it was placed back in the frame, three days later, together with added buoyancy of 40 kg. Although the inflatable buoyancy was cheaper per kilogram of buoyancy and was more compact in its design, it is worth considering polystyrene buoys when this problem of compression is taken into account. The meter mooring of position 2 stayed upright throughout the period of investigation.

The second problem occurred when the moorings were being moved to positions 3 and 4. During this operation a severe storm moved through the area making the movement from position 2 to 4 extremely difficult and the marker buoy attached to the meter frame was lost. The external marker had been moved earlier in the day to position 4. The meter mooring at position 1 was successfully moved to position 3 and retrieved two weeks later.

The mooring frame at position 2 was re-surveyed but despite intensive diving and trawling, the frame was not found. This mishap suggests the need for some release mechanisms (perhaps acoustically operated) on the anchor weights which would allow the frame to rise to the surface when activated.

In general the metering program was successful and meter inspections provided little difficulty in fine weather. The current meters functioned reliably and, with more thought to mooring frame buoyancy types and release mechanisms, the loss of moorings and/or meters could be avoided.

3.2.2 Drogue measurements

a. *Aims-expectations-evaluation*

The aims of the drogue program were to determine the response of the surface waters to wind stress and to provide further information about the internal circulation pattern. The first aim was well illustrated by the drogue measurements but information obtained on the internal circulation, by drogue tracking, was very limited. This part of the program is to meet the second research objective given in Section 1.4.

b. *Type-design-specifications-accuracy*

A drogue consists of a submerged drag device which is suspended at the required depth by a rope and surface float marker. The main principle of drogue design is to minimise the wind drag and other forces so that the movement of the drogue closely represents the path of the water flow at the prescribed depth.

The two drogue designs used in this study are shown in Figure 3.6. The aims of these designs were to have a drogue with a large drag area to surface buoy area^{24,25}, which was easily handled, deployed and retrieved. The ratio of drogue area to surface buoy area was approximately 10:1 which was considered adequate when considerations of the handling ability are taken into account. The metal four-finned drogue, used for wind shear investigations, was calibrated with a current meter and the results are shown below in Table 3.1.

Table 3.1
DROGUE CALIBRATION

Depth	Drogue	Current Meter
3m	3.4 cm/s	3.5 cm/s
6m	2.0 cm/s	2.5 cm/s

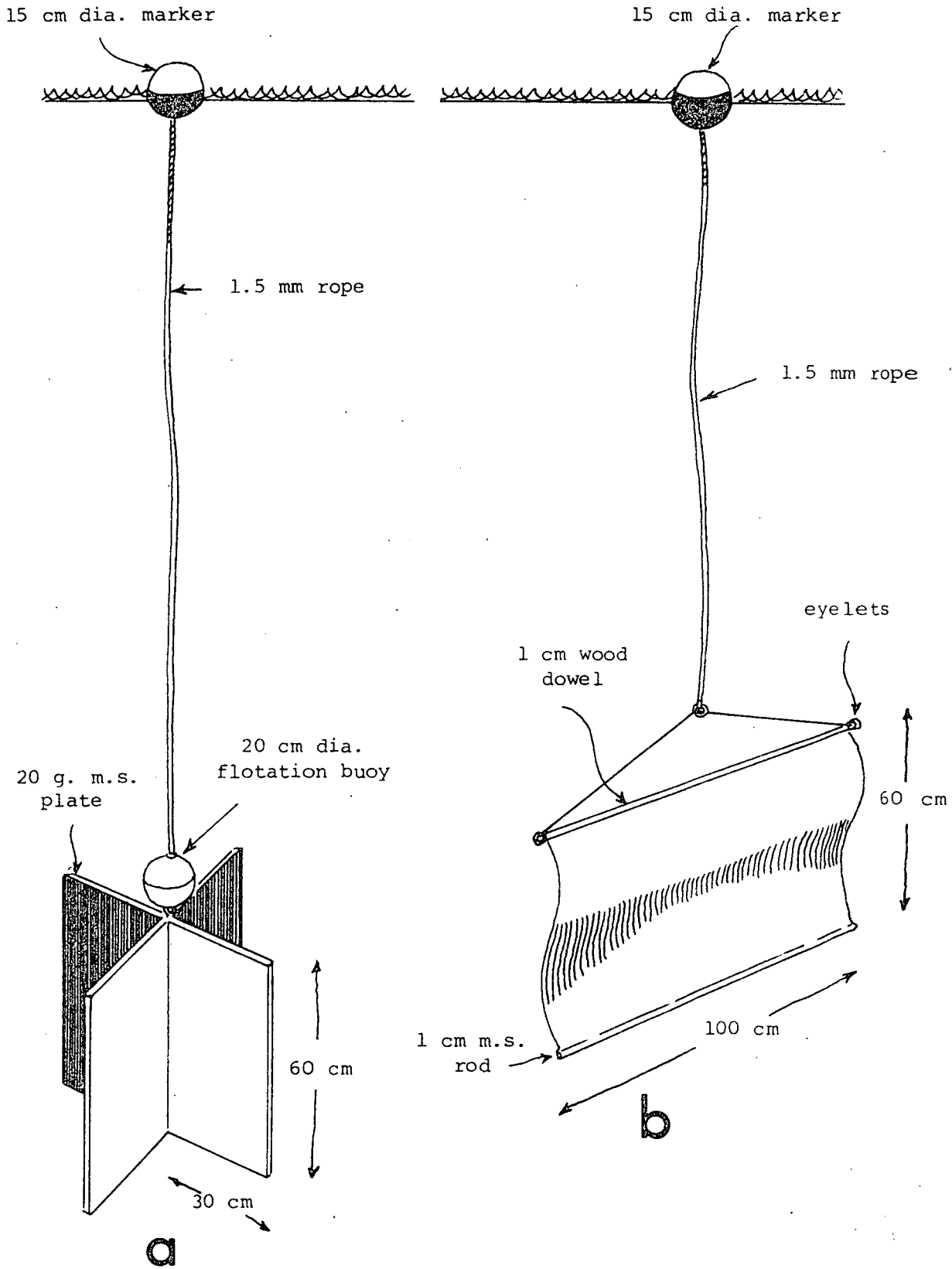


Figure 3.6

Drogue designs :

- (a) four-finned metal drogue
- (b) plastic-blind drogue

These measurements were averaged over the sampling period of approximately half an hour at the two depths. The limitations of this calibration were that it was not achieved over a wider range of velocities and the second calibration at a depth of 6 metres was at the threshold value of the current meter.

The four-finned metal drogue's size and weight made it unsuitable for use from a small boat in open water. This drogue was used for wind stress investigations at the Explosives Jetty within North West Bay. The plastic blind drogue could be rolled up and easily released and retrieved in a small boat. This drogue was used throughout the study area in open water.

The drogue studies of circulation patterns could only be carried out during daylight hours and on average the tracking time was six hours. The distance that drogues travelled during these investigations varied with drogue depth and wind conditions and ranged from approximately 1000 metres for the surface drogue to approximately 400 metres for the 15 metre drogue.

A sextant was used to fix the position of the drogues. Sightings were made to well defined land marks which were well distributed around the bay.

Experience with the use of the sextant indicated that an accuracy within one degree could be relied upon, giving an error in the actual drogue position of approximately 50 metres for a central position within the bay. For the surface drogues tracked over a four hour period, the approximate velocity error would be ± 0.4 cm/s.

c. Deployment-location-sampling-depth

The wind shear investigations at the Explosives Jetty measured currents at depths of 0, 2 and 5 metres below the surface.

The plastic blind drogues were used for investigations in deep water throughout the study area, at depths of 0, 2, 5,

10 and 15 metres below the surface, and were tracked with a sextant from the boat to known shore stations.

During all drogue investigations, wind measurements were made with a portable, counter type wind meter. These measurements of wind speed and direction were made at a distance of 2 metres above the water surface.

d. *Limitations-problems-recommendations*

The greatest problem with the drogue program was tracking. Sextant tracking from a small boat proved difficult in rough weather, and was further exacerbated in overcast conditions which made it difficult to find the marker buoys.

In these respects the use of theodolites from land-based stations with a small boat moving around to drogues as a marker point would have been a more desirable technique if the manpower was available. To utilise the advantage of this type of measurement technique, tracking over a long period of time is essential, together with the release of a large number of drogues over a wide area.

3.2.3 Salinity-temperature measurements

a. *Aims-expectations-evaluation*

The broad aims of the salinity-temperature measurement program were to, provide a time sequence of salinity-temperature characteristics so that the gross exchange and rates of the bay could be calculated, and the extent of the influence of other local water bodies such as the Derwent and Huon estuaries could be investigated. These were the third and fourth objectives given in Section 1.4. Few practical difficulties were encountered with these measurements and the results are given in Section 4.2.

b. *Type-design-specification-accuracy*

A Yellow Springs, model 33, portable salinity temperature meter was used for salinity-temperature investigations. The accuracy of this instrument is given as 0.2‰ for salinity and 0.15°C for temperature. The total accuracy taken for the temperature-salinity data was 0.3‰ for salinity and 0.3°C for temperature which is sufficient for the interpretations and conclusions drawn from this data. The probe used with the temperature salinity meter was a platinized nickel electrode type in a rigid p.v.c. body with a thermistor temperature sensor. To keep measurement errors to a minimum, a standard seawater sample of known salinity was used to calibrate the instrument before and during field investigations.

c. *Deployment-location-sampling depth*

Salinity-temperature measurements were made throughout the study area from a small boat. Initially 33 salinity sampling stations were chosen within North West Bay and the associated D'Entrecasteaux Channel area. These sampling stations were initially fixed with a sextant and marked with a plastic float attached to a light line and anchor. The positions of these sample stations are shown in Figure 3.7. Because of the time involved in completing all sampling points and the nature of the gross exchange calculations that were to be made from the salinity-temperature data, the number of stations was reduced to 13 which covered the main channel transects within North West Bay and the D'Entrecasteaux Channel. These stations are shown in Figure 3.8.

The sampling program ran from May till September, being most intensive during August. In general measurements were taken at depths of 0, 1, 2, 5, 8, 11 and 14 metres from the water body surface, although on some occasions a longer probe was available allowing sampling to a depth of 27 metres. The sampling sequence was such that measurements were taken as the probe was lowered. The probe

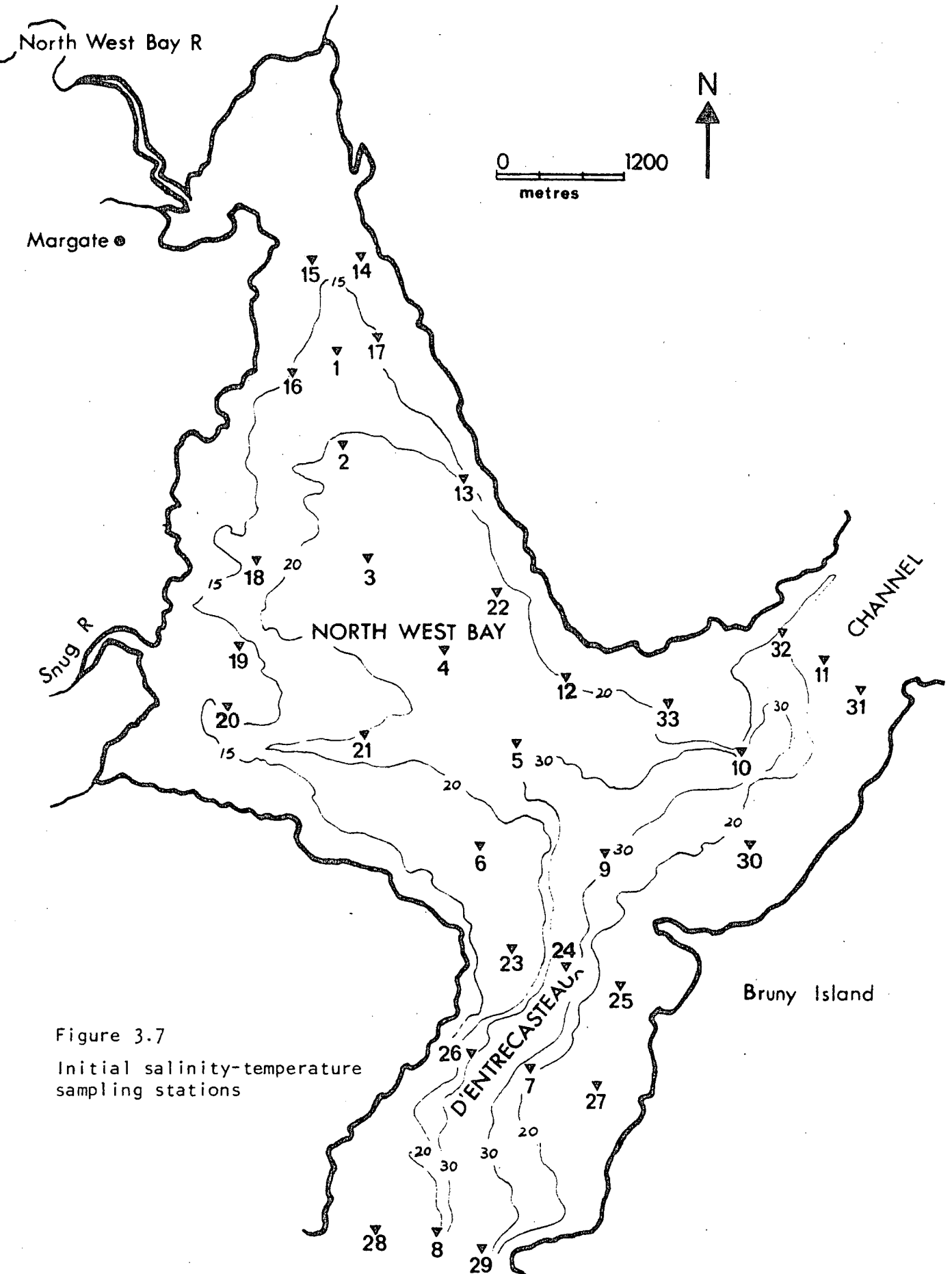


Figure 3.7

Initial salinity-temperature
sampling stations

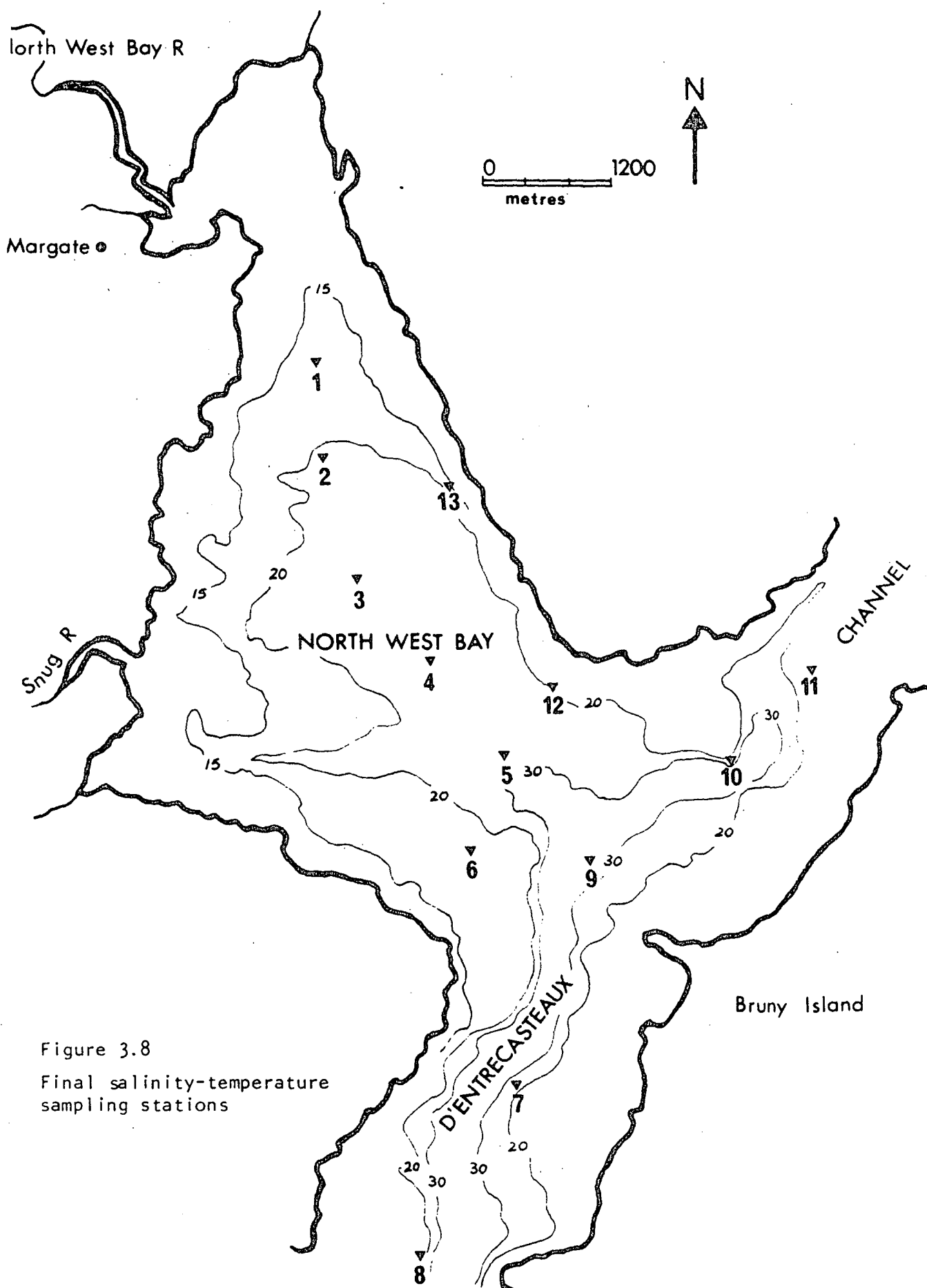


Figure 3.8

Final salinity-temperature
sampling stations

was then brought back to the surface where a check reading was taken.

d. *Limitations-problems*

The salinity-temperature measurement program was very successful with few practical problems encountered. The main difficulty occurred when storms passed through the area while measurements were being made. In these cases it proved impossible to anchor the boat at the sampling stations and on odd occasions the proposed field investigation was cancelled.

Another problem that occurred periodically in the D'Entrecasteaux Channel was the drag placed on the probe by currents. On two occasions, the drag on the probe was so severe that only surface measurements could be made. This occurred on quite calm days at Dennes Point, station number 11, and Tinderbox Point, station number 12, with the current running out into the Derwent estuary.

3.2.4 Tide monitoring

a. *Aims-expectations-evaluation*

The aims of the tide monitoring program were: to determine if there were any significant anomalies with respect to the progression of the tide within the bay; to ascertain the presence and magnitude of wind set and seiches within the bay; and to determine the nature and relative degree of the astronomical and meteorological driving mechanisms within the study area. This work would reinforce the first objective as given in Section 1.4.

Although a number of tide sticks were constructed for deployment around the bay, their use was found to be impracticable because of the man hours involved. Thus their use was restricted to the Explosives Jetty during wind shear investigations.

A continuous tide recorder was constructed to obtain a 29 day record during August so that an analysis of the tidal components could be made. Due to recorder malfunction, a continuous record that would be suitable for analysis was not obtained.

b. *Type-design-specification-accuracy*

Two types of tide gauges were built and used in this study.

The first was a simple tide stick made from a 3 cm diameter clear plastic tube, with a plastic measurement tape fastened to the outside of the tube. The bottom end of the tube was sealed and a small 2 mm diameter hole provided for damping. A polystyrene marker float was used inside the tube. A continuous recording tide gauge was constructed to record tide levels within the bay during the month of August. This gauge utilised a pressure transducer type LX1902G from National Semiconductor Corporation¹¹⁴. The pressure transducer was housed in a probe and positioned 5 metres below the water surface on a jetty pylon. The recording mechanism was fastened beneath the jetty well above high water level. Details of the recording circuit and probe design are given in Figures 3.9 and 3.10.

The pressure transducer probe was vented to the atmosphere via a plastic tube so that only the pressure due to the height of the water column above the probe was sensed. The transducer produced a linear voltage output of 2.5-12.5v for a pressure variation of 0-15 p.s.i. This gave a gradient of 1v output per 1.5 p.s.i. pressure. The water pressure on the transducer varies only slightly with salinity and temperature and is approximately 1.46 p.s.i./metre of sea water at salinity 35‰ and temperature 10°C.

As the transducer probe was placed approximately 5 metres below the water surface, a static output of approximately 7v was obtained about which the tidal variation occurred. As the maximum tidal range expected in the area was 1.5

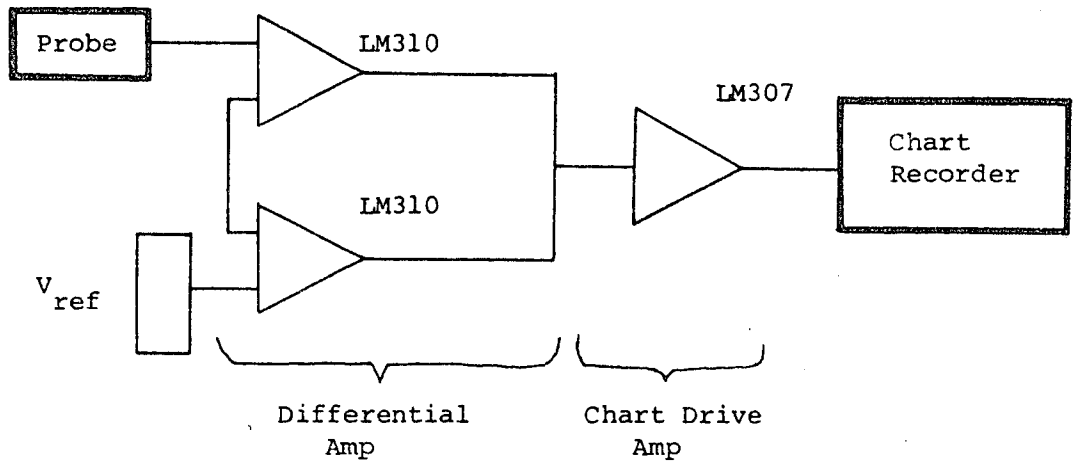


Figure 3.9 Circuit schematic: tide gauge

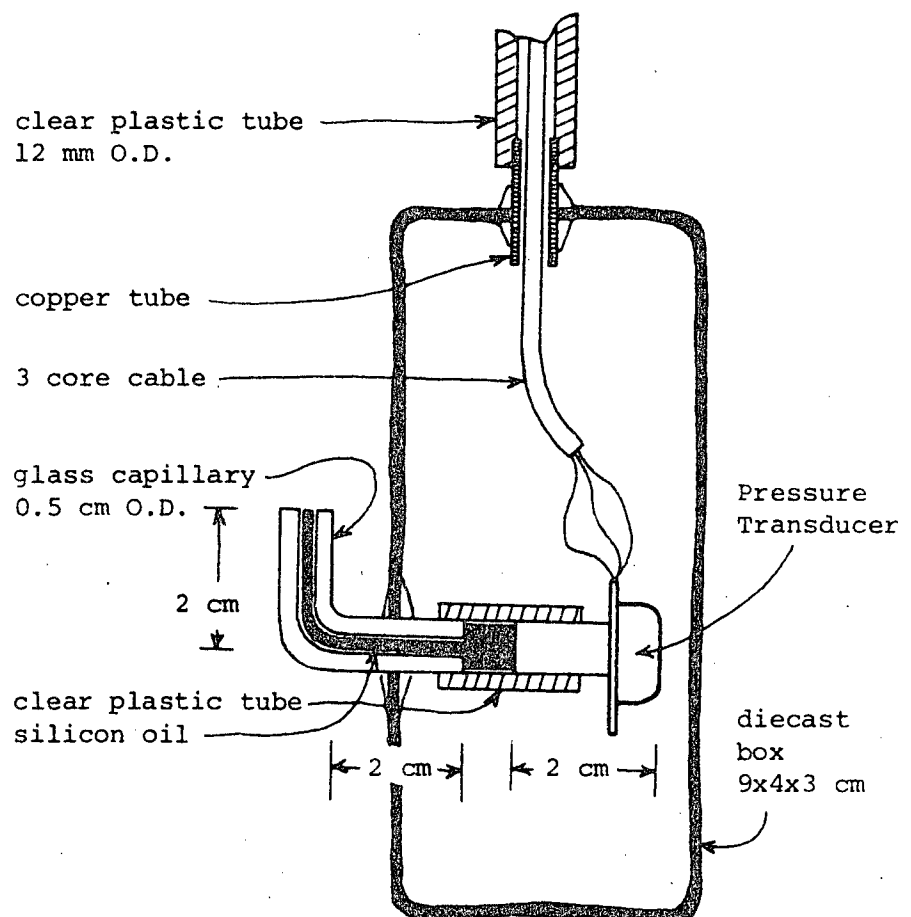


Figure 3.10 Pressure transducer probe

metres the transducer output voltage variation was approximately 1v. The recording circuits utilised a differential amplifier to eliminate the static output with respect to a reference voltage source and the difference voltage was fed to a chart recorder. The recorder was calibrated so that a 3 metre variation in water level produced a chart recorder output variation of 5 mA. This range of possible variation provided ample scope for the monitoring differing levels due to meteorological variables such as wind set and barometric pressure.

c. Deployment-sampling rate

The continuous tide recorder was attached to the Explosives Jetty within the bay. The sampling rate was determined by the dot chart recorder which impressed a sample upon the chart every two seconds. Chart speeds of 10, 6 and 1 inch per hour were used at various times to provide range of detail in the records.

d. Limitations-problems-recommendations

Difficulties encountered with the tide stick included the manpower requirements, and the difficulty of accurately reading the stick in strong swell or choppy conditions. With the continuous recording tide gauge significant problems occurred with the recording circuitry and chart recorder. These included: the chart recorder gear train working out of mesh; the record chart being caught in the mechanism and breaking; and the portable batteries becoming flat, altering the recording reference voltage, and causing a drift in the tide record.

The most desirable design change with this tide gauge would be to eliminate the need for a reference voltage source and record the pressure transducer output directly through the use of a microprocessor or a magnetic tape recording.

3.2.5 Meteorological variables

a. *Wind*

A continuous recording wind station was not available in the study area, although wind measurements were conducted when drogue studies were being carried out. To ascertain the broad scale wind effects on the water mass, the wind records for Hobart (see Figure 2.1) were obtained for correlation with the current meter records.

b. *Barometric pressure*

A portable, clockwork barometric pressure recorder was installed in the study area at Margate (see Figure 2.2) for the month of August while current meter investigations were being carried out. This information was used to assess the influence of local pressure systems.

3.3 Data Processing and Presentation

The raw data obtained in this study required a considerable amount of processing both for analysis and presentation. This section discusses the techniques used in the data processing and also the spectral analysis of the current meter records.

3.3.1 Current meter data

As the raw current meter data was in the form of an inked impression on a paper tape, a number of fortran programs were used for the presentation and evaluation of this data.

Histogram plots of current meter velocity and direction were used to evaluate patterns and trends in the data record. The directional nature of the data was determined from histogram plot of direction frequencies. As the directional error is greater at lower current velocities, a direction frequency table for various velocity classes was also obtained.

For the purpose of spectral analysis the current meter data was resolved into so called north-south (ns) and east-west (ew) components according to :

$$ns_t = v_t \cos(\xi_t + \theta)$$

$$ew_t = v_t \sin(\xi_t + \phi)$$

where ns_t and ew_t are the resolved components for sample time t , v_t and ξ_t the velocity and direction values at time t . θ and ϕ are the resolution angles with respect to true north.

As an example, the histogram of direction frequencies and its velocity class structure, for one of the current meter records, is shown in Figure 3.11. This histogram has a binodal character with peaks at 120° and 335° . A value of $\theta = \phi = -40^\circ$ would be chosen so that the data was resolved about an orthogonal axis, as shown below in Figure 3.12. The current meter direction is the direction in which the current is *going to*.

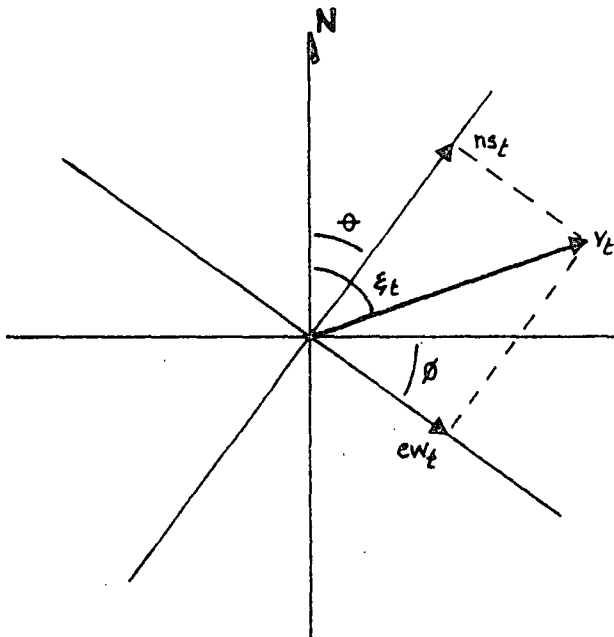


Figure 2.12 Resolution axis

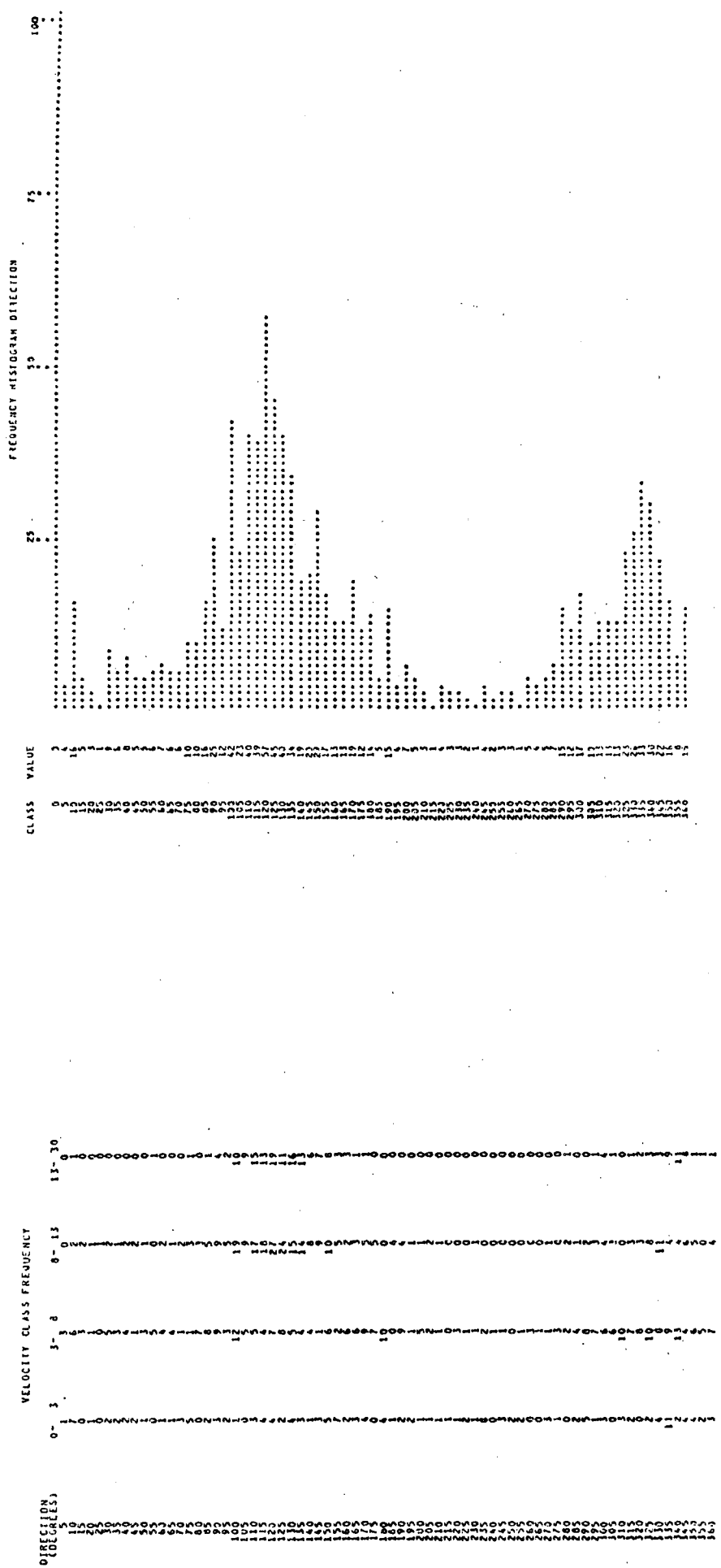


Figure 3.11 Meter No. 1 direction frequencies

To determine the nature of the driving mechanisms reflected in the current meter record, a spectral analysis of the resolved data was carried out using IMSL library programs on the Burroughs B6700 computer at the University of Tasmania.

The method available was a spectral estimate using Blackman-Tukey techniques utilising a *Parzen* filtering window. The method requires the initial choice of a wide bandwidth window to delineate the broad spectrum character. This window is then presented with smaller bandwidth to elucidate the finer detail of the spectrum until a point is reached where continued narrowing of bandwidth reveals no more detail, or instability of the estimates produces indiscriminate results. This method enables the best bandwidth to be chosen to suit the available record and in part relies upon a knowledge of the spectral properties of the record.

The use of the *Parzen* window is an attempt to minimise the leakage effects of the simple boxcar truncation method. The *Parzen* window is slightly wider than other windows such as *Hann* and *Hamming* and has an effective standardised bandwidth of

$$B_e = \frac{1.86}{M\Delta}$$

M = truncation point of the time domain record

Δ = sampling rate in sec.

This means that its resolution is less than other windows but the statistical variability is reduced. The *Parzen* window also produces slightly biased but positive spectral estimates. The number of degrees of freedom for the *Parzen* spectral estimate is given by

$$\gamma = 3.71 \frac{T}{M}$$

T = record length

M = *Parzen* truncation point

The spectral program was tested using the first 400 terms of a second order auto-regressive process

$$x_t = x_{t-1} - 0.5x_{t-2} + z_t$$

given by Jenkins and Watts¹²¹. This process has a theoretical spectrum peak at $f_0 = 0.125/\Delta\text{Hz}$, and the results of the analysis are given in Figure 3.13.

This analysis shows that the peak is well represented for $M = 16$ with double peaks occurring either side of the true frequency as the bandwidth is further reduced when $M = 32$. This gives some doubt about the true spectrum for $M = 32$ unless some prior knowledge of the spectrum is available. Detailed accounts of the theoretical and practical aspects of spectral analysis of time series data are given by Jenkins and Watts¹¹⁶, Newland¹¹⁷ and Otnes and Enockson¹¹⁸.

3.3.2 Drogue data

The results of wind stress investigations are presented graphically. The variables plotted include drogue speeds and direction at various depths, tide data and wind data. The wind direction is where the wind is *coming from* while the current direction is where the current is *going to*. For circulation studies, drogue tracks are presented on a scaled map of the study area together with wind and tide details. The start and finish positions of drogue tracks were fixed by sextant and the intermediate track determined by visual observation.

3.3.3 Tide data

Because of the difficulties encountered with the tide monitoring program, a full 29 day record was not obtained for the use of traditional regression analysis techniques given by Dronkers^{77,78} and Easton^{79,80}.

A preliminary comparison of the observed tidal times and heights in North West Bay was made with the predicted tides of Department of Defence (Navy Office)¹¹⁹ and the Hobart

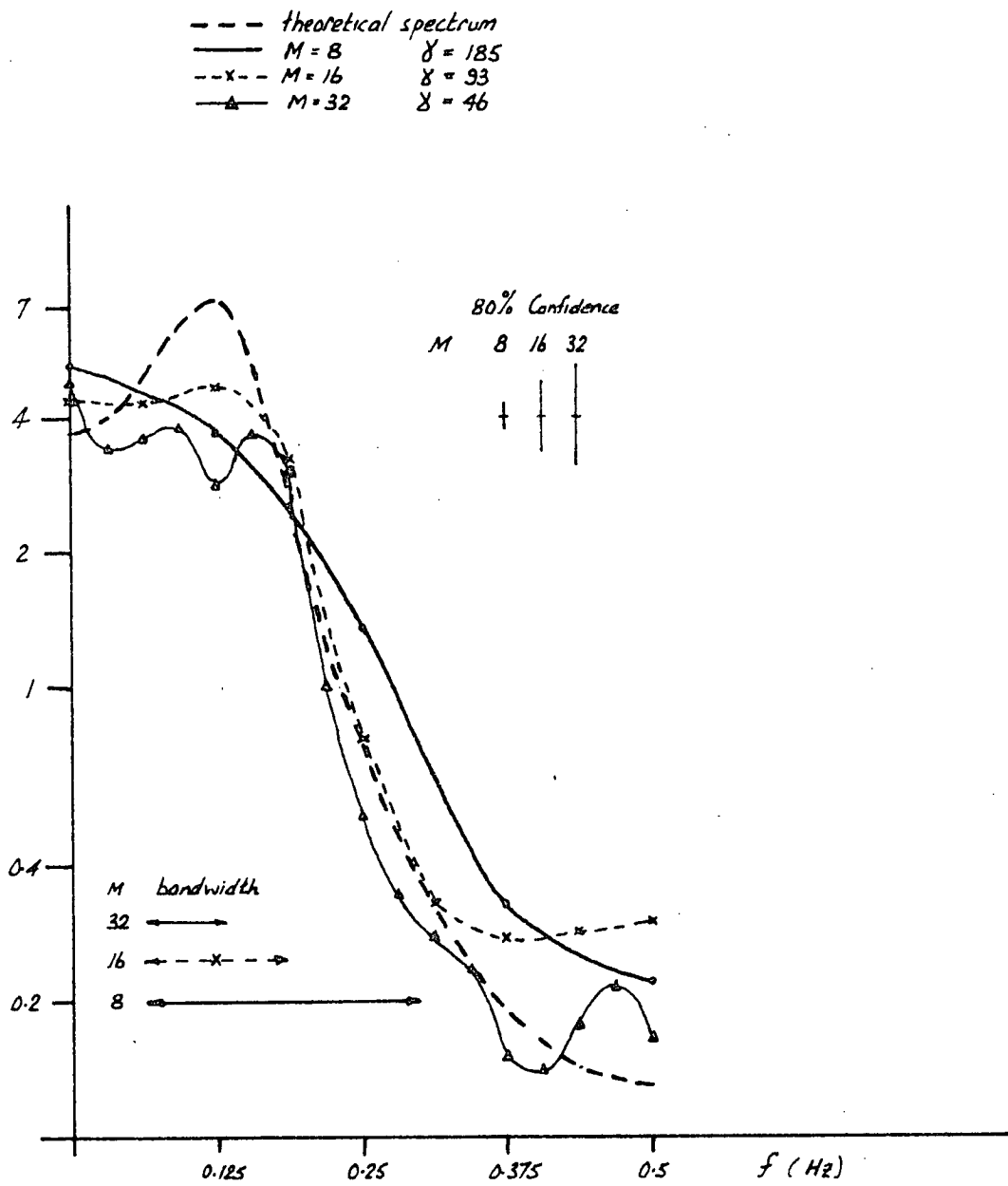


Figure 3.13

Spectral analysis - test data

tide record from the Marine Board of Hobart for the month of August.

3.3.4 Salinity-temperature data

Part of this data is presented as a number of cross sectional profiles of salinity, temperature and density, with contour interval of 0.5 units. Densities were determined from a nomogram given by Dietrich³³.

The salinity-temperature data was used to estimate the exchange characteristics and freshwater content of the bay.

3.3.5 Wind and barometric pressure data

All wind data gathered was presented graphically with velocity in metres/second (m/s). Directions are where the wind *came from* at the standard 16 compass points.

Wind data obtained within the study area was recorded at five minute intervals, while that obtained from Hobart is based on spot samples at one hour intervals.

Barometric pressure data obtained at Margate was plotted at three hour intervals. A spectral analysis of this data was obtained for comparison with the spectral properties of the current meter data.

3.4 Summary

- . A range of techniques have been reviewed in order to assess their suitability for use in North West Bay.
- . The techniques and equipment used in this study have been discussed and their limitations evaluated.
- . The processing required for the analysis and presentation of data has been examined with particular emphasis on spectral analysis.
- . Many of the problems encountered in constructing and deploying equipment for this study have been highlighted.

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4

study results

4. STUDY RESULTS

Information gathered in this study is presented in three sections, each of which has a distinct theme. Thus a summary of the main points has been incorporated at the end of each section.

- . The first section examines driving mechanisms and is thus mostly concerned with current meter and drogue data.
- . In the next section, emphasis is placed upon the salinity temperature data from which inferences are drawn on the rates of water exchange, rates of mixing and influences of other estuarine waters.
- . The final section constructs some preliminary hypothesis of circulatory patterns and also considers some phenomena not discussed in the preceding sections.

4.1 Driving Mechanisms

The circulation patterns that occur in a water body are a response to the combined effects of driving mechanisms such as tides, meteorological forces, and fresh water inflows. The magnitude of these mechanisms varies in time and space and if their relative importance is to be determined, continuous monitoring over a significant time period is required. In some cases, mechanisms, such as wind stress, are dominant in a limited region of the water body and their characteristics may be determined in relative isolation from other mechanisms. The second objective outlined in Section 1.4 was to look at this phenomenon.

This section of the report presents an analysis of the circulation data for North West Bay so that the relative significance of the driving mechanism can be determined. This data consists of drogue and current meter measurements.

4.1.1 Drogue data

To determine the significance of wind stress as a driving mechanism in North West Bay, drogues were used to ascertain:

- . a range of co-efficients for a simple linear relation between the wind speed 2 m above the surface and the surface wind-drift current.
- . the nature of the wind-drift profile and the depth to which wind stress has a significant influence.
- . the nature of the response of the water surface to varying wind direction and speed.

Wind stress investigations A (Figure 4.2) and B (Figure 4.3) were conducted at the Explosives Jetty (Figure 4.1), within North West Bay.

Investigation A was carried out during a high tide period so that the effects of tidal currents would be minimal. The wind pattern varied markedly from a moderate north-westerly wind in the morning to a south-easterly sea breeze, with one strong gust, in the afternoon. The currents observed were in sympathy with the wind pattern and no distinct tidal component was apparent.

The surface current responded quickly to changes in wind direction and speed as indicated by the direction change at 1400 hrs, and the wind and surface current velocity peaks at 1000, 1300 and 1600 hrs.

The drift current profile exhibited a logarithmic nature during times of strong wind velocities as shown by the profile at 1600 hrs when a strong gust of 22 m/s passed through the area. At other times the influence of wind stress is still apparent but the profile exhibits a 'mixed' character suggesting other influences. The ratio of wind-drift surface current (u_s) to wind velocity (u_w) was approximately 0.01 at 1300 and 1600 hrs, the times of wind velocity peaks.

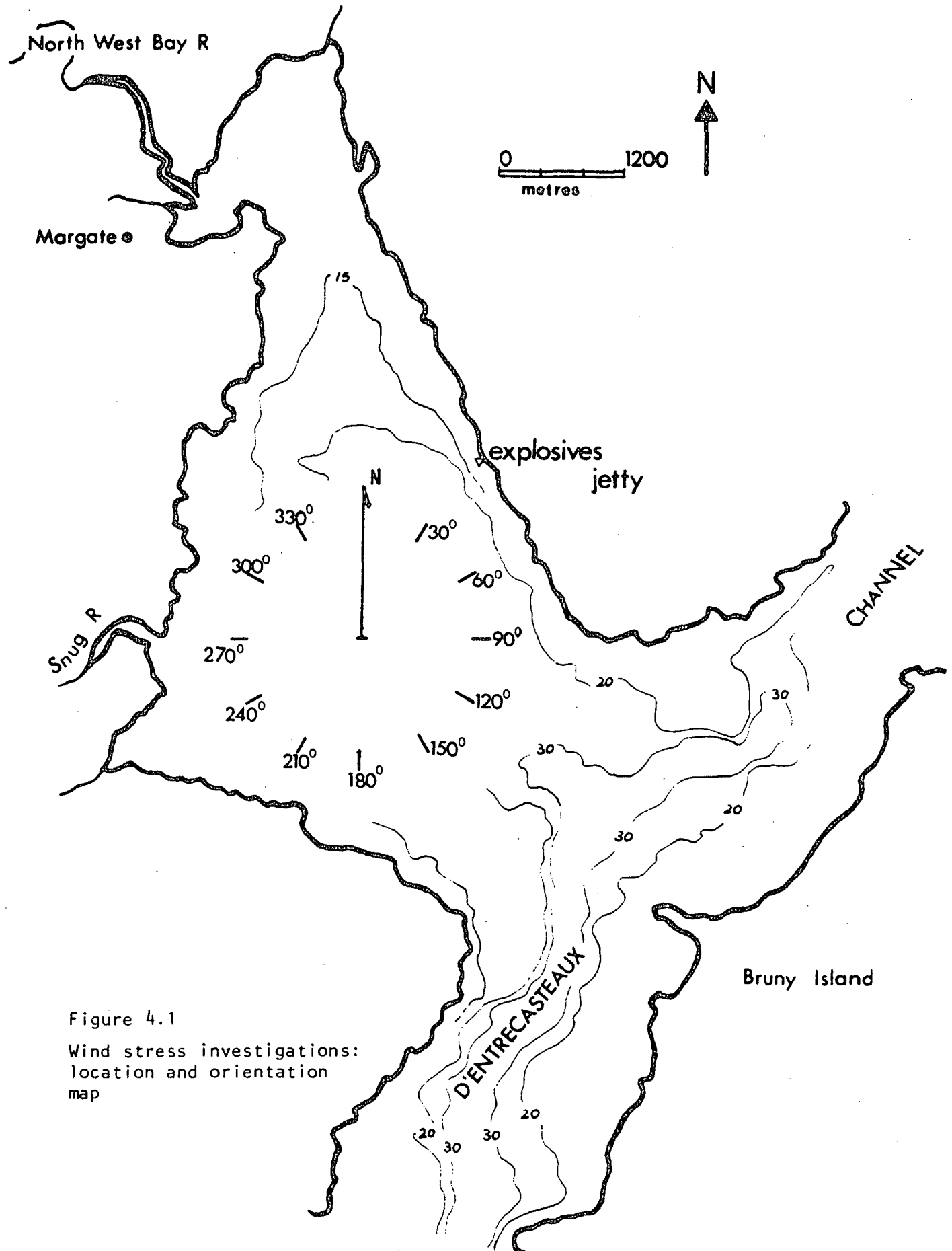
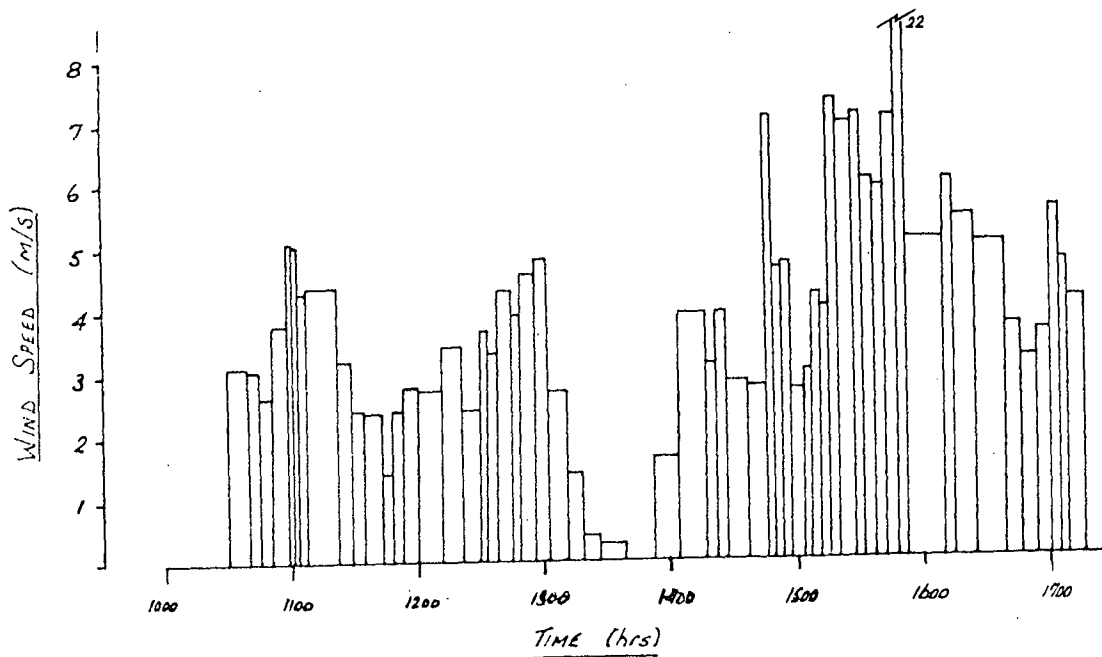
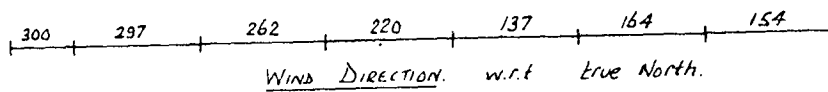
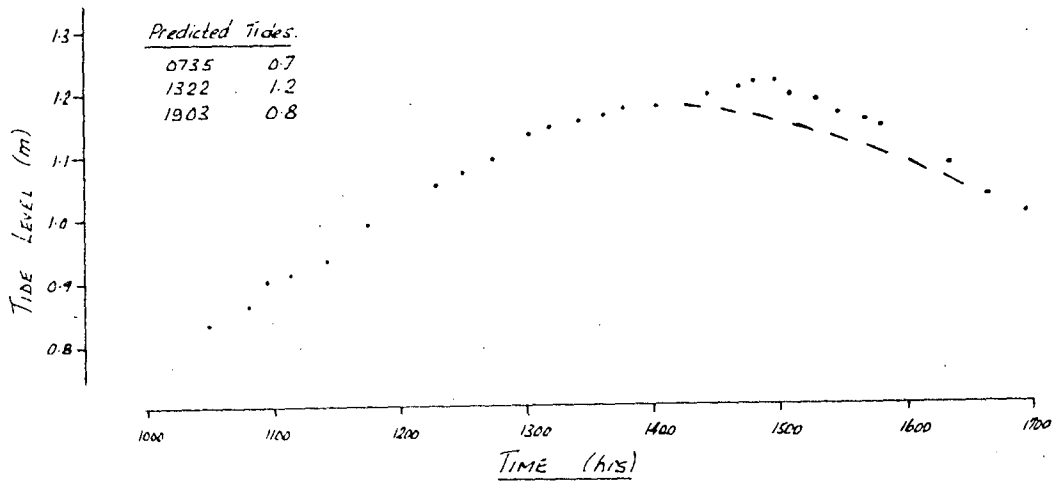


Figure 4.1

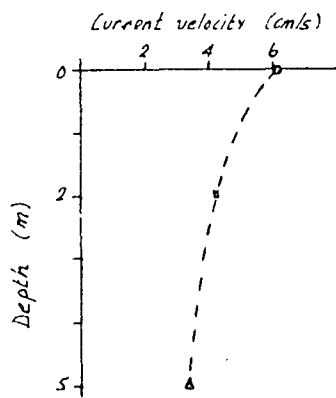
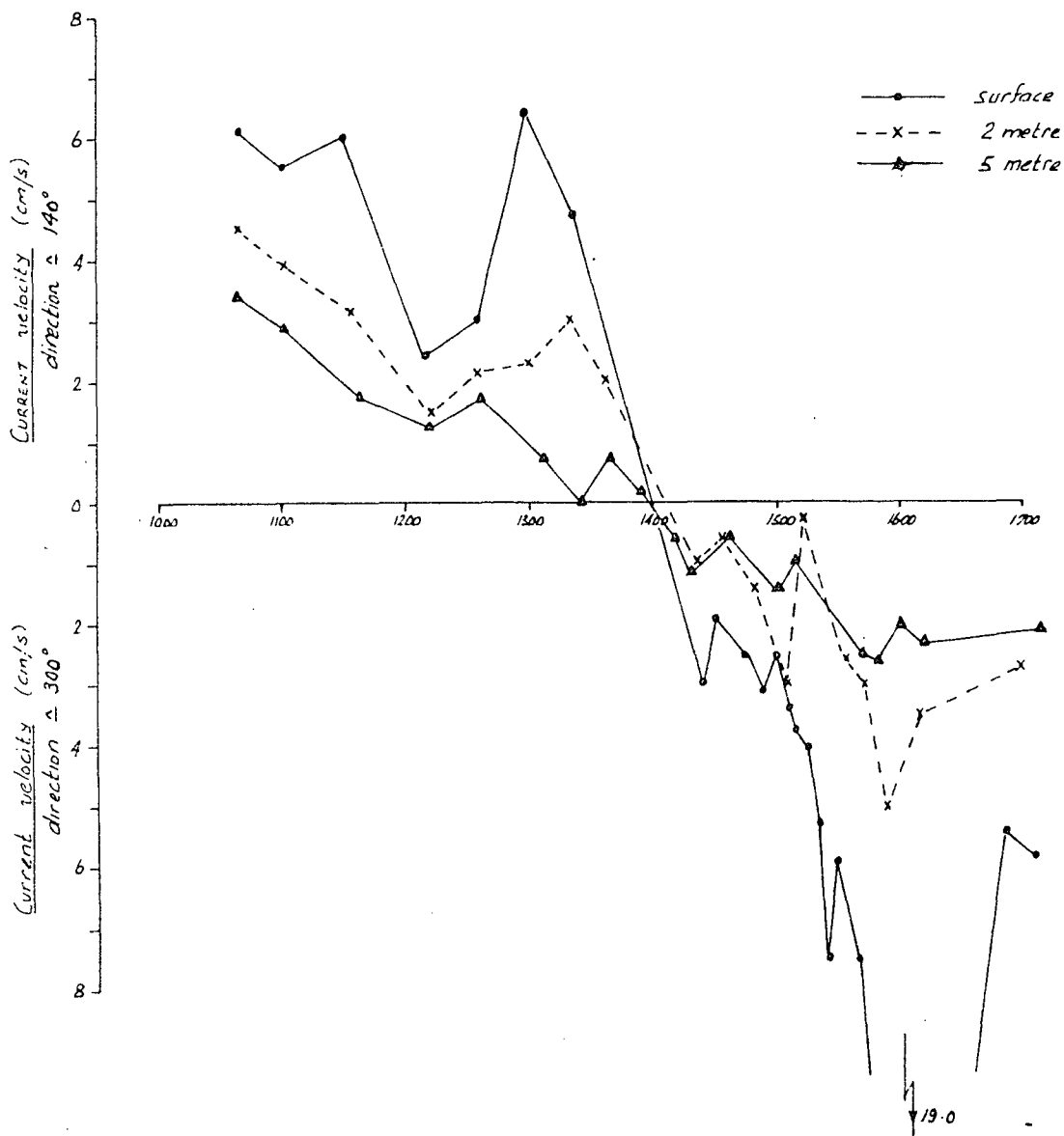
Wind stress investigations:
location and orientation
map



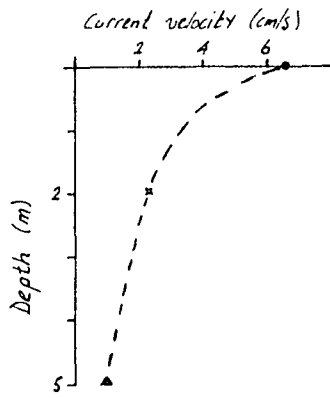
Current velocity (cm/s)
direction - 140°

Current velocity (cm/s)
direction - 300°

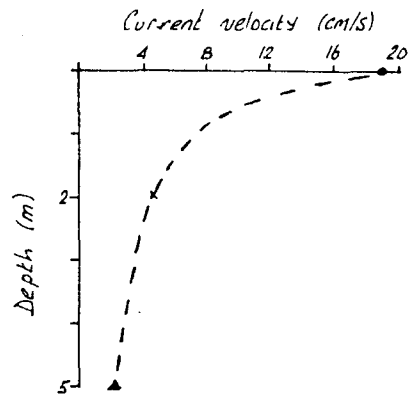
Depth (m)



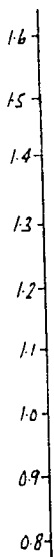
PROFILE 1030



PROFILE 1300

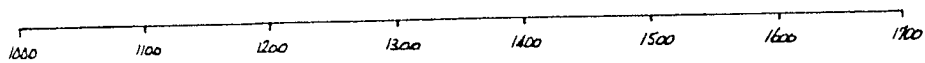


PROFILE 1600

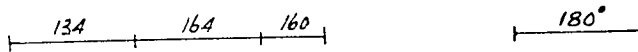


Predicted Tides

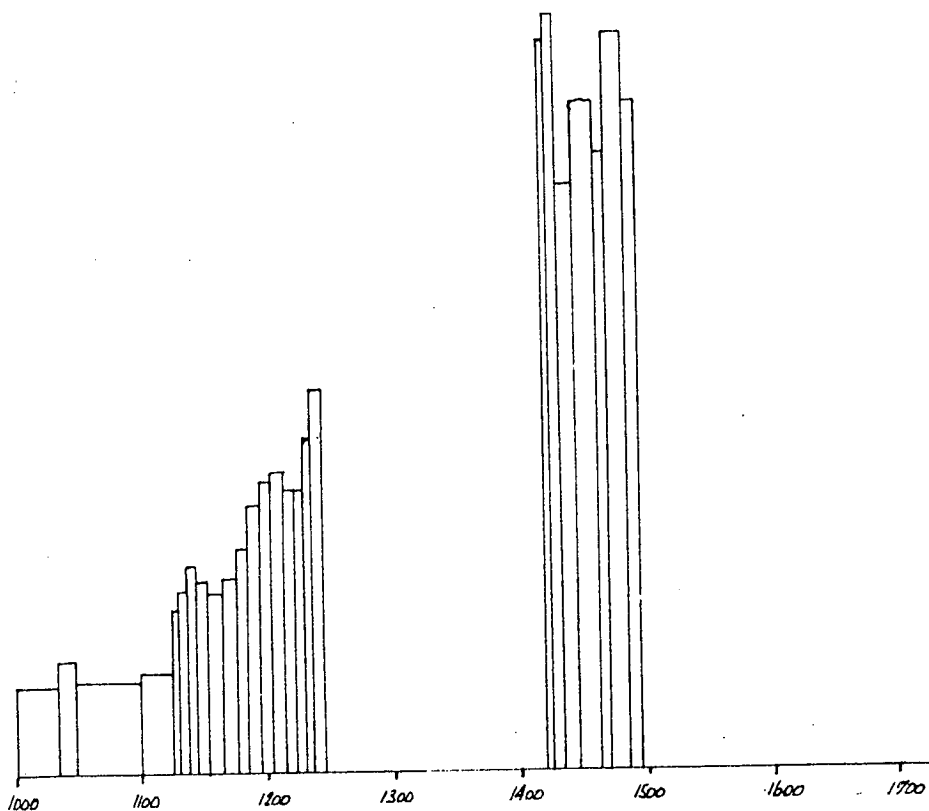
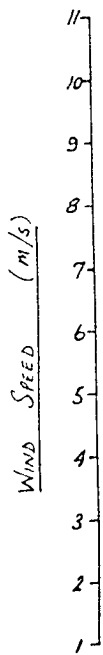
0739	1.5
1443	0.6
2109	1.2



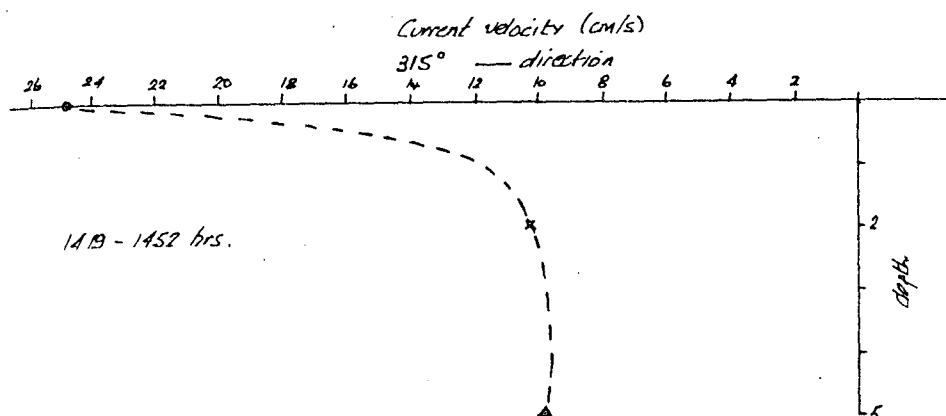
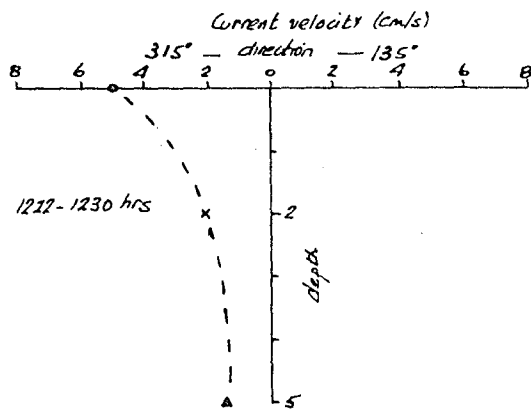
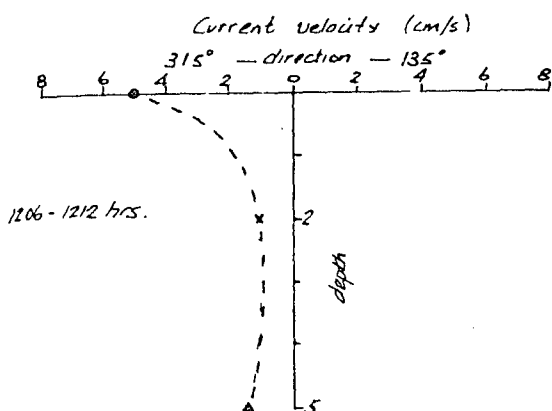
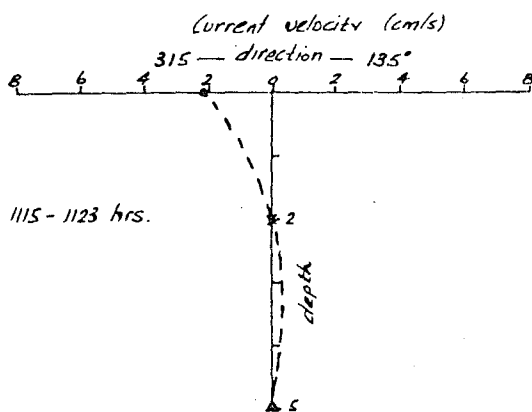
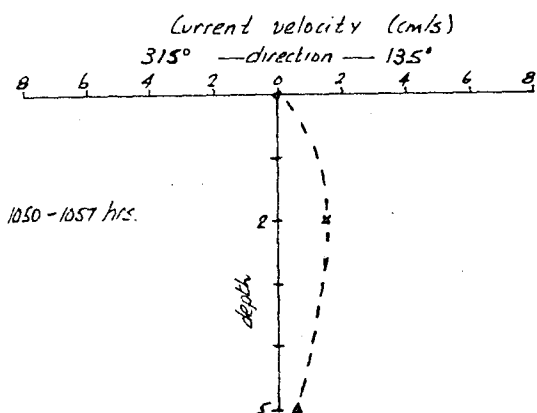
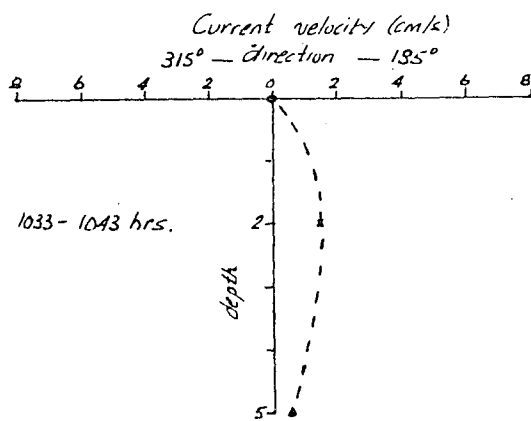
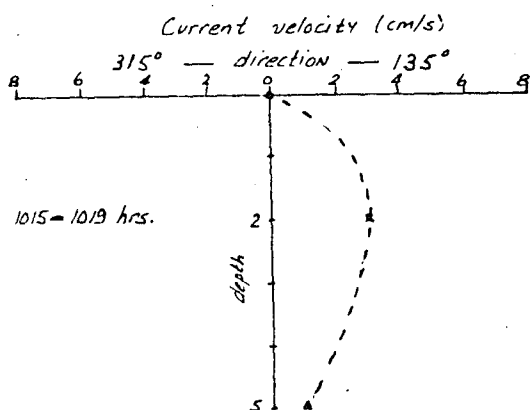
TIME (hrs)



WIND DIRECTION (wrt true North)



TIME (hrs)



Although the current drift at a depth of 5 m responds to the wind direction change, its magnitude is relatively small and has little response to wind velocity. The wind-stress effects beyond this depth are not considered to be significant with respect to the effects of other mechanisms. It should also be noted that an appreciable amount of wind set occurred on the tide level during the south-easterly winds from 1430-1630 hrs.

Investigation B was carried out during a period of ebb tide, and illustrates the response of the water body to a gradually increasing, and a strong sustained, wind-stress. The effects of other mechanisms is also illustrated in this investigation.

The wind direction was south-easterly with velocities increasing to a strong sustained wind in the afternoon. From 1000-1100 hrs the low wind speeds of less than 2 m/s kept surface drift to a minimum with an ebb current occurring at 2 m depth. As the wind speed built up from 1100-1230 hrs the wind-drift current increased in the direction of the wind, and exhibited a mixed profile. During the period 1400-1500 hrs, a strong sustained wind produced significant surface drift currents with large currents at 5 m depths thought to be due to other causes and not to the direct influence of wind-stress.

The current drift profiles at 1230 and 1450 hrs give a u_s/u_w ratio of 0.01 and 0.04 respectively. The larger value at 1450 together with the increased currents at greater depths, is the response to a strong but sustained southerly wind which may have created a distinct longshore drift along the eastern shore of the bay. This theory is further reinforced when one considers that the wind-drift current continued in its direction to 315° while the wind direction was coming from $160-180^\circ$.

Investigations A and B were carried out in a nearshore and relatively shallow area. To help with the evaluation of wind-stress effects in North West Bay, the tracks of drogues

in open waters should also be considered.

The drogue tracks of six investigations (C - H) are shown in Figures 4.4 to 4.9 respectively. As these drogue tracks were taken over approximately four hours, the velocities represent an average response to wind-stress and other mechanisms.

All investigations show a significant effect of wind-stress on surface drogues with the obvious influence of other mechanisms at depths of 5 metres and greater.

In general the surface wind-drift was in sympathy with the wind direction with some anomalies being present in investigations E and C. These anomalies could be due to the combined effects of other forces such as wind set on the western shore of the bay. These average results indicate a range of u_s/u_w ratios of 0.01 to 0.04.

The limited open water drogue tracks of this study do not give conclusive evidence for determination of surface circulation patterns due to wind-stress, and more intensive work is required in this area of investigation.

The conclusions that may be drawn from the drogue investigations are:

- . The undisturbed wind-drift profile appears to be logarithmic in nature but the effects of other mechanisms can alter this profile significantly. The surface wind-drift current may vary from 0.01 to 0.04 of the wind speed measured 2 metres above the water surface.
- Other studies¹⁻⁸, conducted in coastal waters and lakes indicate that the pure wind-drift profile is logarithmic and the surface wind-drift may be 0.033 of the wind speed measured 1 metre above the water surface.
- . The surface wind-drift current responds quickly to significant changes in wind speed and direction over a short period of time.

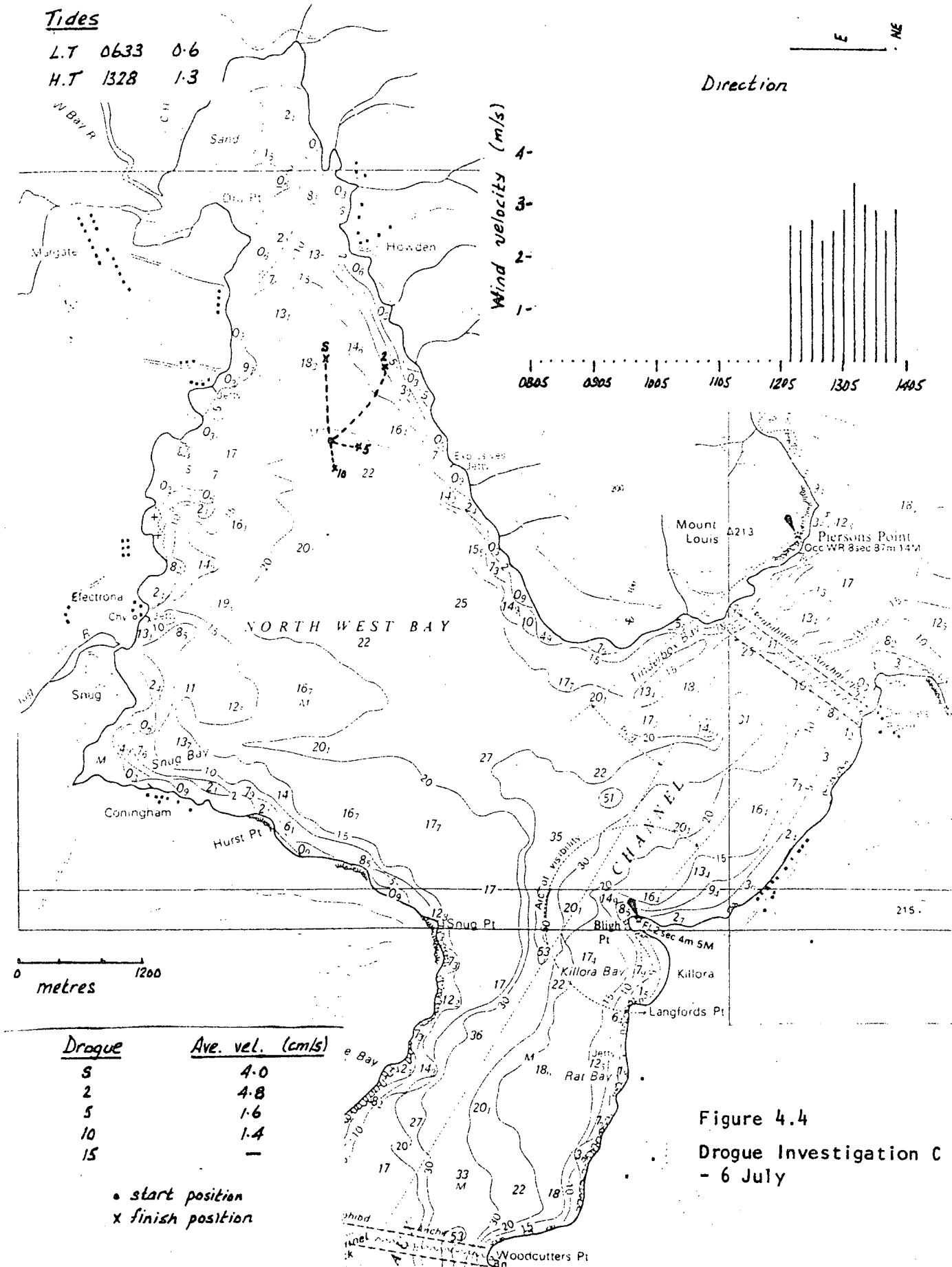


Figure 4.4
Drogue Investigation C
- 6 July

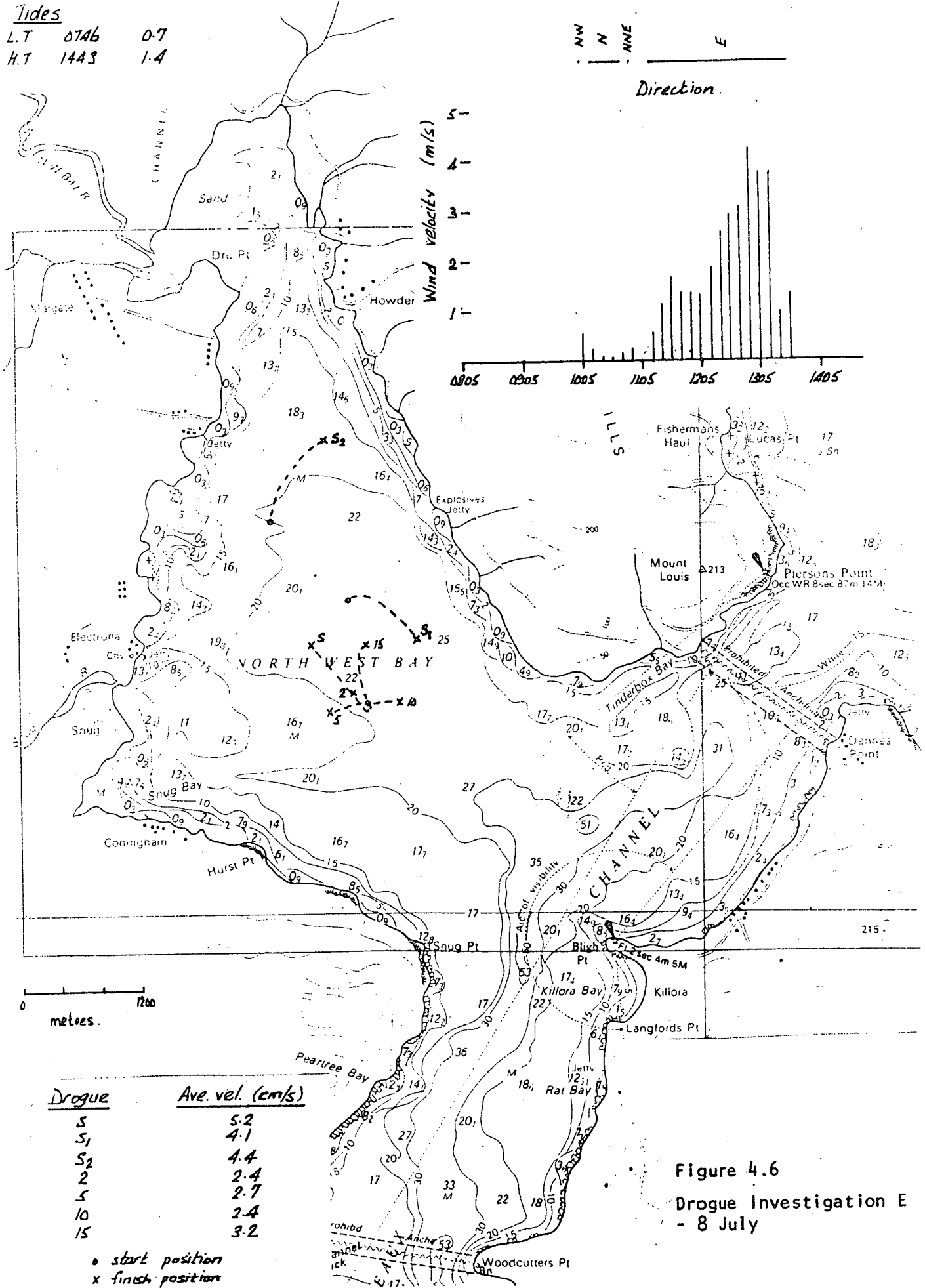
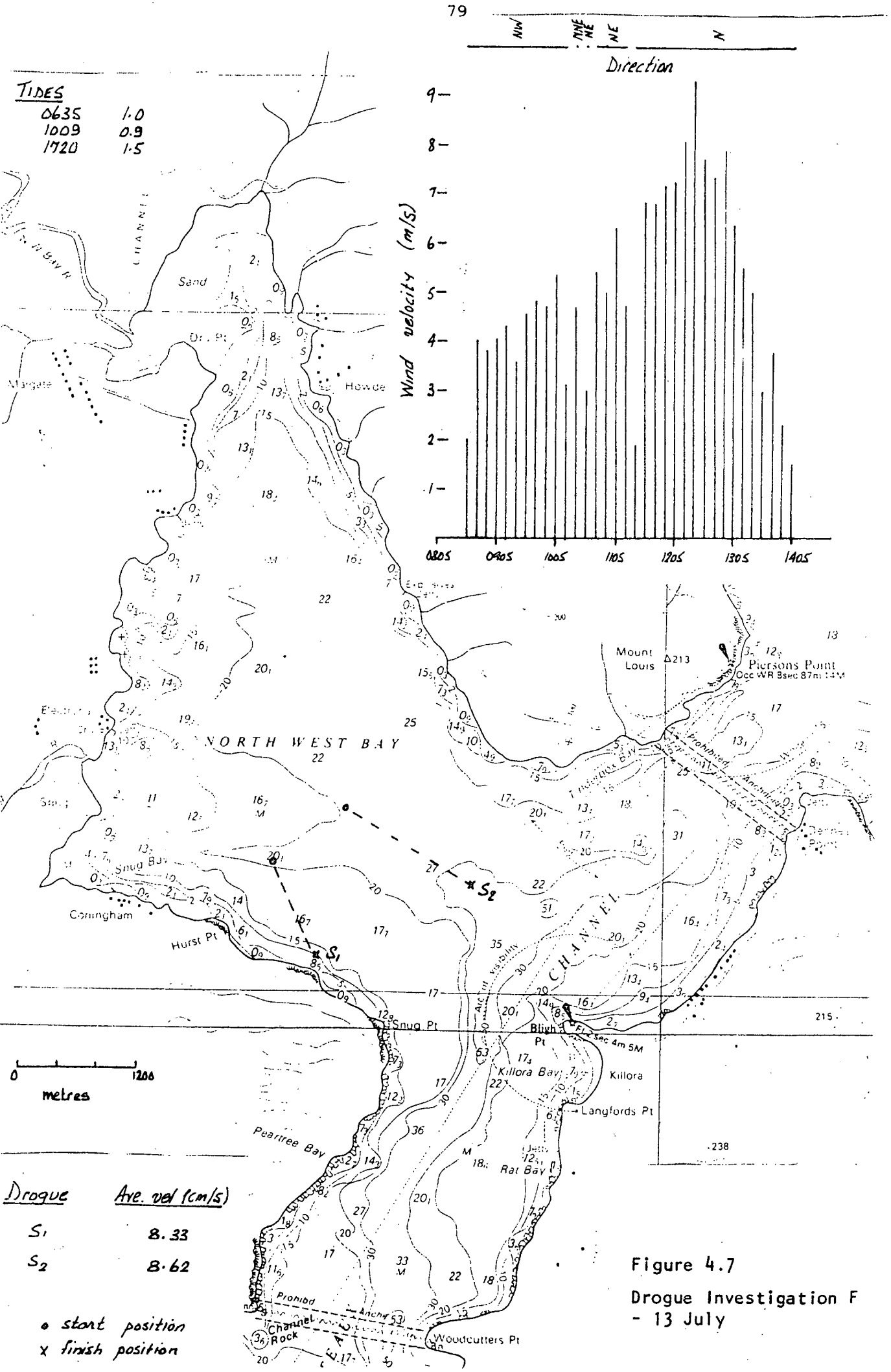
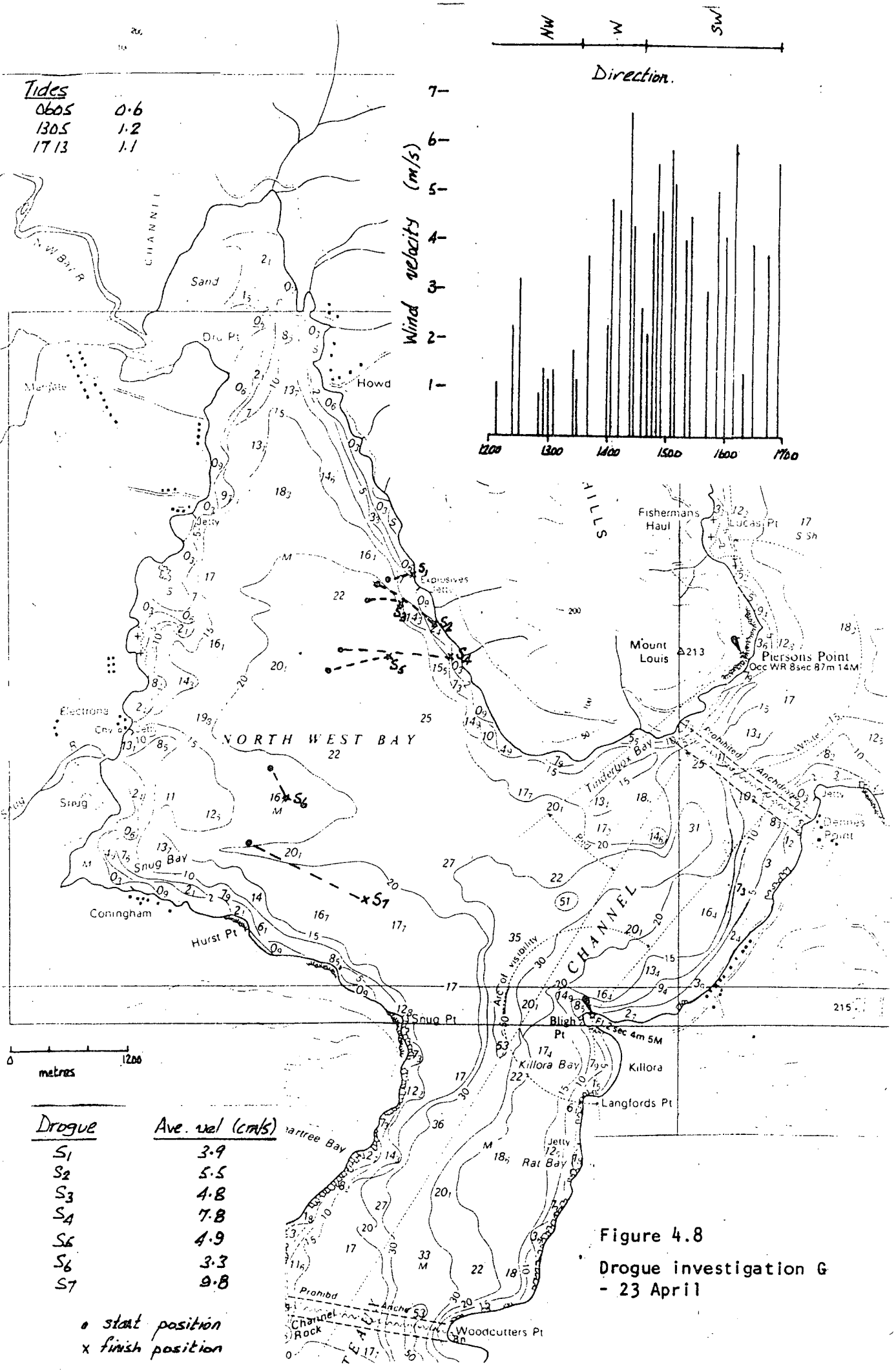


Figure 4.6

Drogue Investigation E
- 8 July





TIDES

1105 1.2
1515 1.0

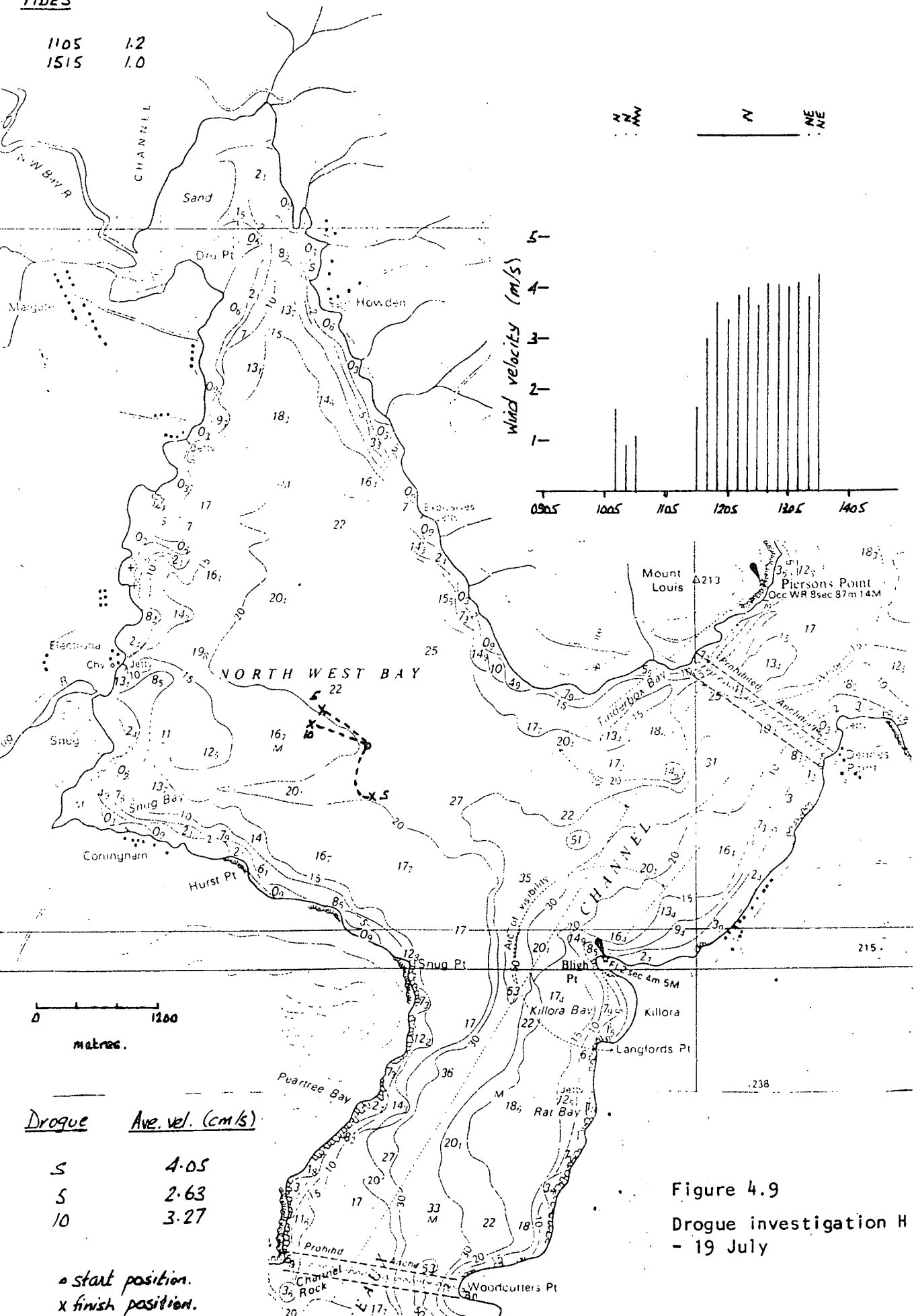


Figure 4.9

Droque investigation H
- 19 July

- . The variability of drogue direction and velocity with respect to depth indicates that the wind-stress is significant in the surface layers but other mechanisms have significant effect at depths greater than 5 metres.
- . Wind-stress effects in North West Bay are only significant in the surface layers. There is some evidence to suggest that long shore drifts may develop under sustained winds.
- . The wind shear driving mechanism is considered to have little effect on the majority of the water mass and in effect acts as a transient mixing mechanism via surface and small deep water return currents to restore the mass balance within the bay.

4.1.2 Current meter data

Current metering was conducted at two locations across the entrance to North West Bay for a period of four weeks. The meters were located at mid depth so that the effects of direct wind shear would be minimal and the resultant data could be used to evaluate the relative significance of tidal and meteorological driving mechanisms on the bulk of the water mass. This was the first objective as given in Section 1.4.

For ease of presentation, the current meter data is presented as hourly averages of current velocity and direction in Figures 4.10 to 4.12. Spectral analysis was carried out on the original current meter data (see Section 3.3.1) and the results are presented in Figures 4.13 (Meter No. 1), 4.14 (Meter No. 2) and 4.15 (Meter No. 3). The record lengths used for these analyses were 2084 for Meter No. 2 and 1024 for Meters No. 1 and 3.

The broad scale spectrum characteristics for all meters indicate that the majority of the energy is concentrated at very low frequencies, and in fact, over 97% of the total energy is at periods greater than eight hours.

When the spectrum at periods greater than eight hours is investigated in greater detail, three significant groupings of energy occur. The energy content of the spectrum for various period classes is shown below in Table 4.1.

Table 4.1

PERCENTAGE ENERGY CONTENT IN VARIOUS PERIOD CLASSES

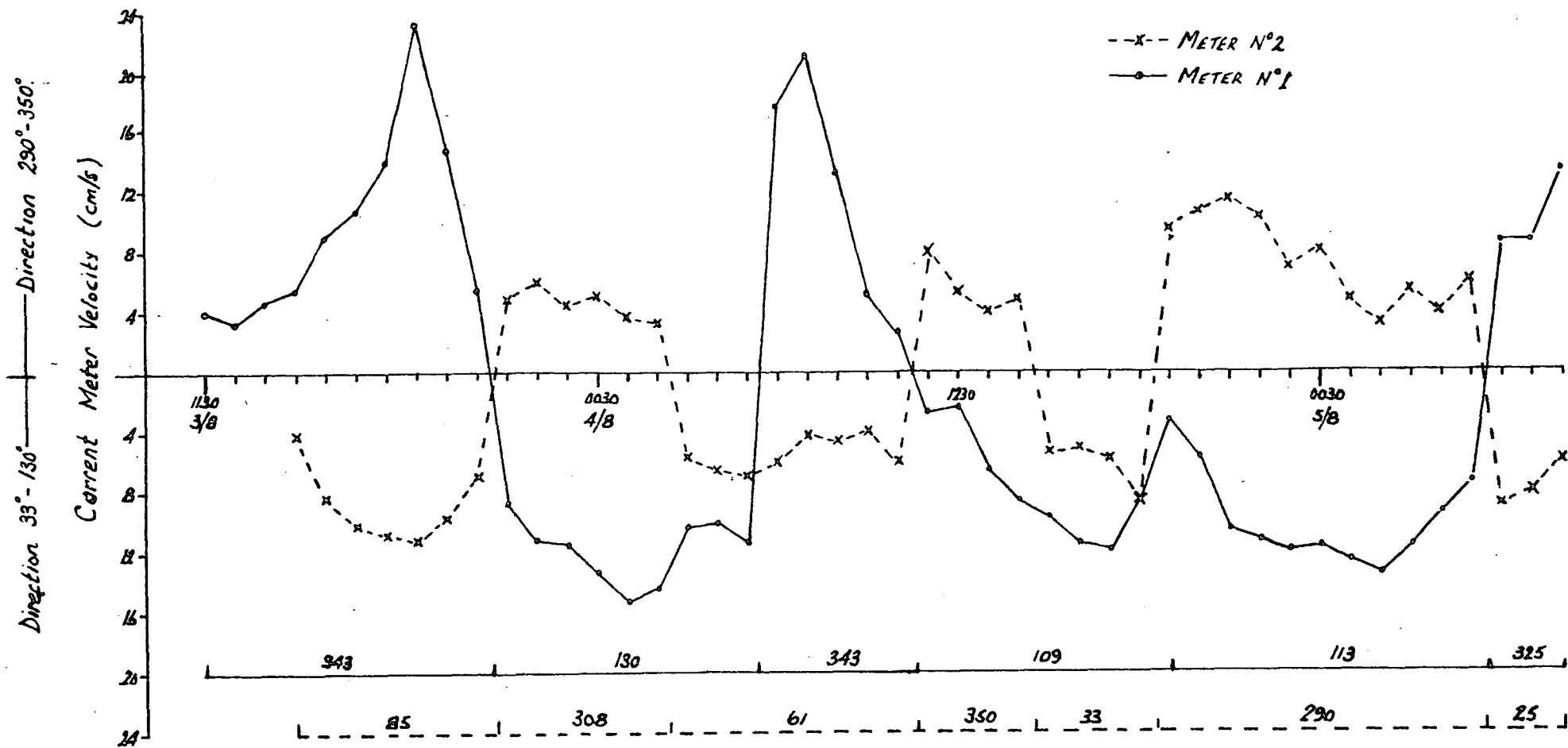
Meter No. 2 N=2084 M=1024		PERIOD CLASS (hrs)			
		>28.4	16-28.4	10.6-16	8-10.6
	% Energy	60	28	9	3

Meter No. 1 N=1024 M=512		PERIOD CLASS (hrs)			
		>32	16-32	10.6-16	8-10.6
	% Energy	21	44	23	12
Meter No. 3 N=1024 M=512	% Energy	57	18	17	8

The two shorter period peaks centred at approximately 23.3 hours and 12.2 hours are characteristic of diurnal and semi-diurnal tidal driving mechanisms. The energy content in these two classes indicates that the diurnal mechanism is dominant, containing approximately twice the power content than the semi-diurnal driving mechanism.

These results are reinforced by Easton⁹ who concludes from the analysis of the Hobart tide record that the tides of the Hobart zone are mixed and predominantly diurnal. He classified the tides of this zone as 'microtidal', having a

Figure 4.10
Averaged current meter records
3 - 5 Aug.



Predicted Tide

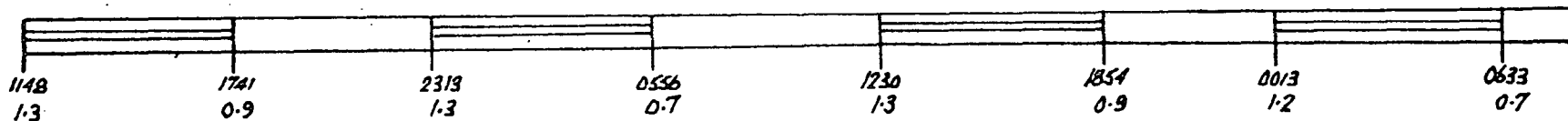
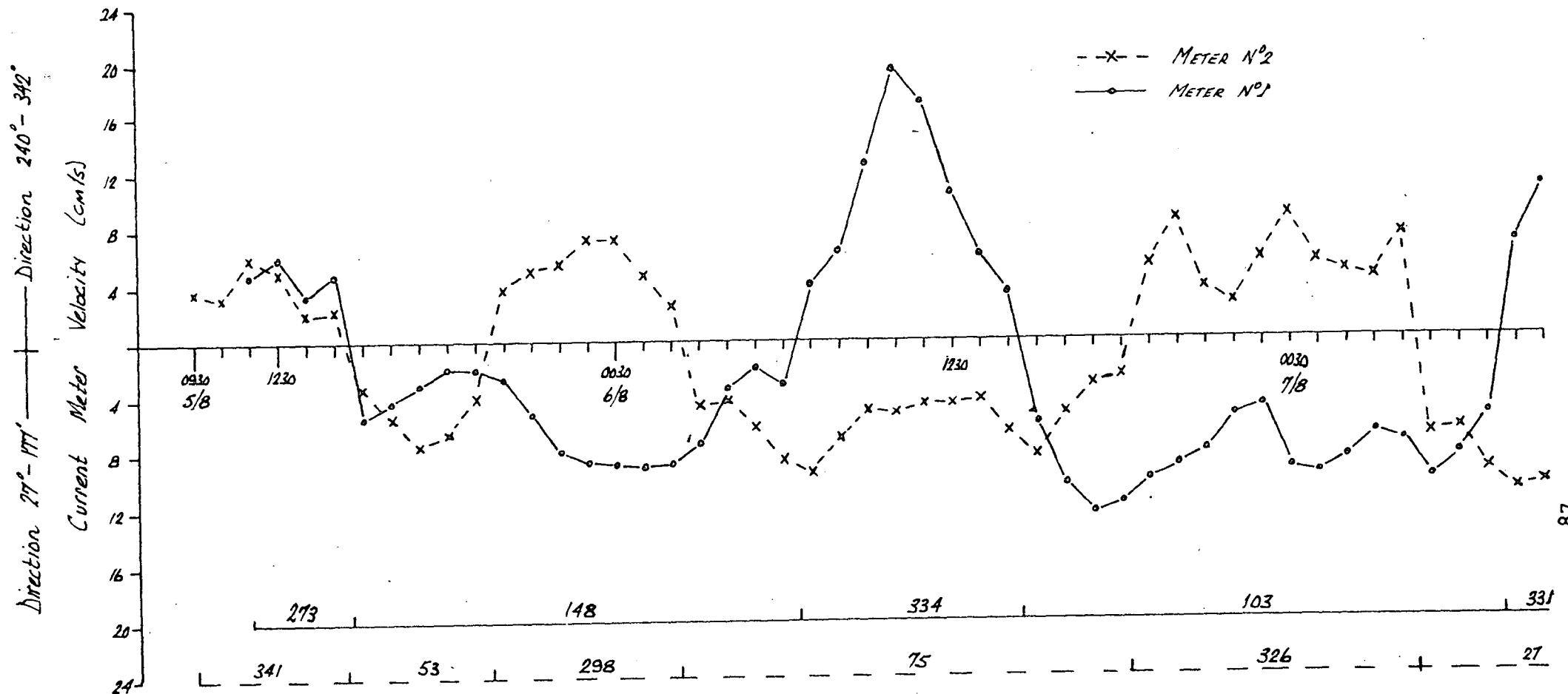
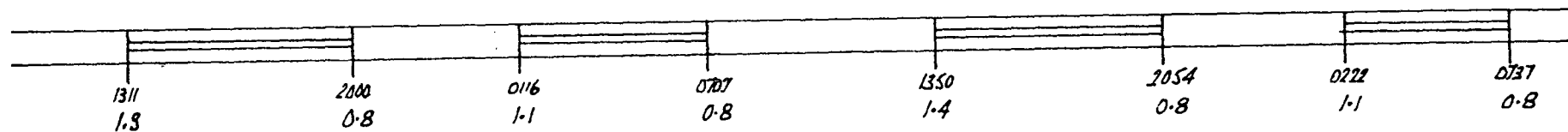
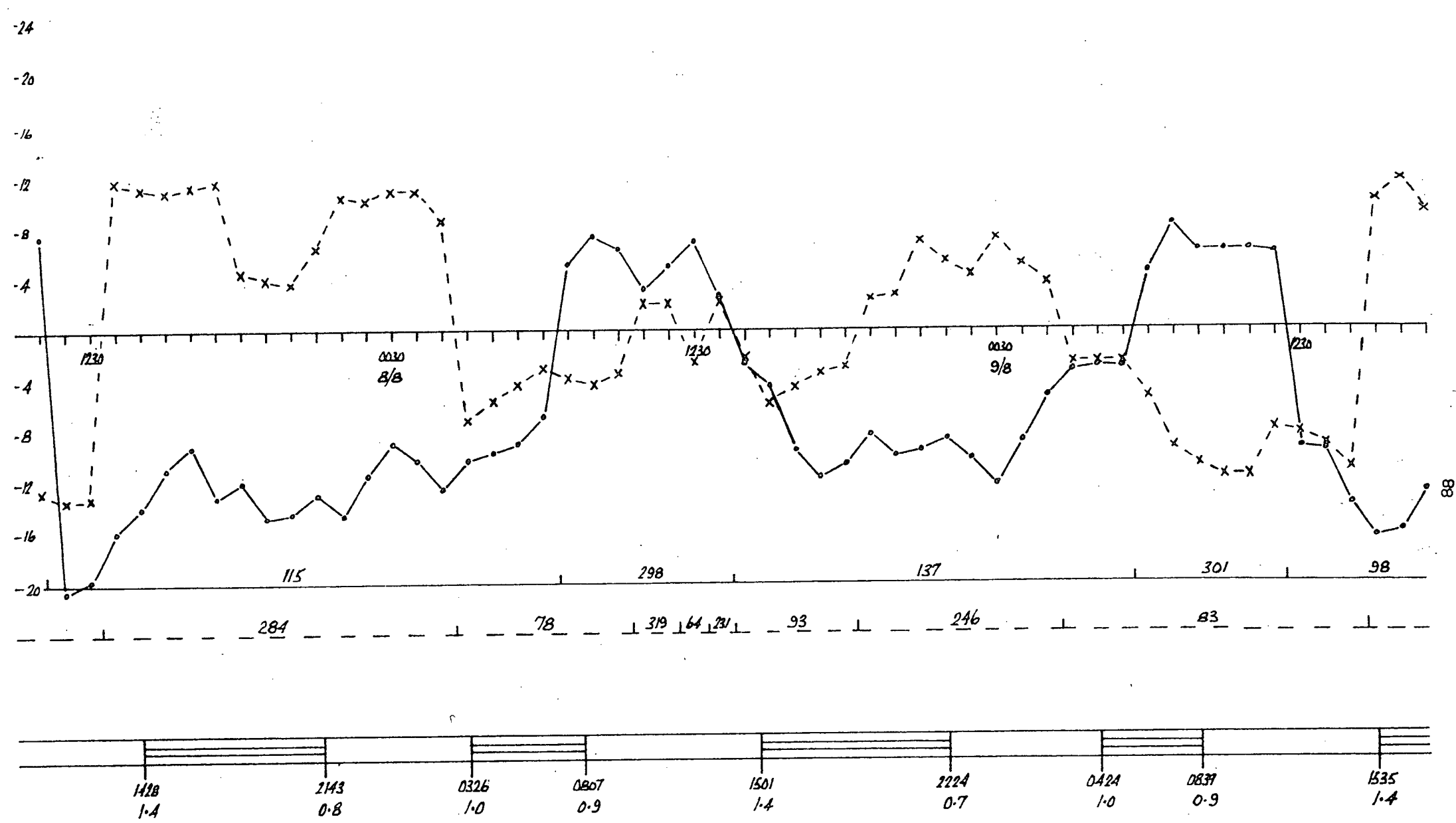


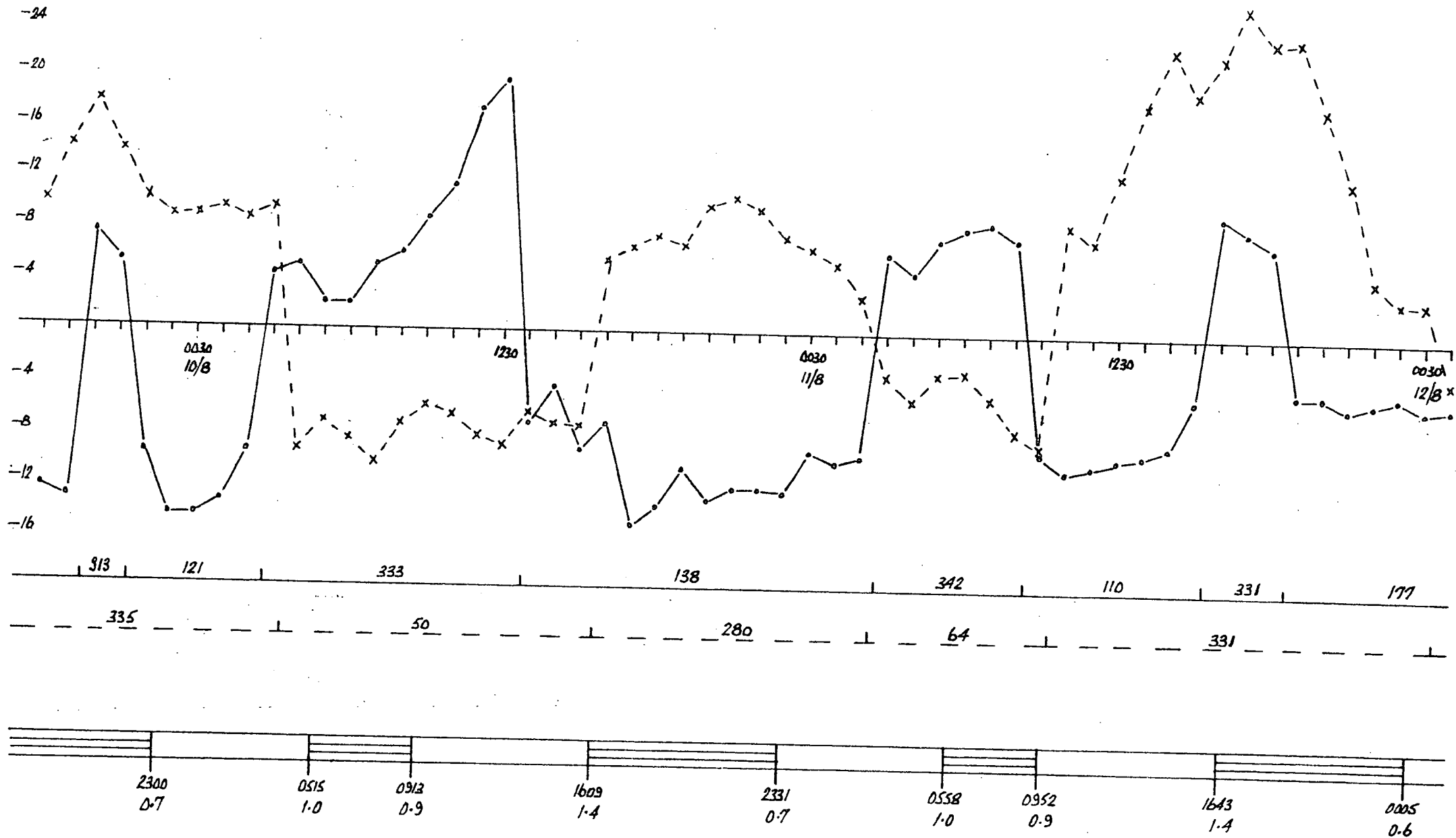
Figure 4.11
Averaged current meter records
5 - 19 Aug.

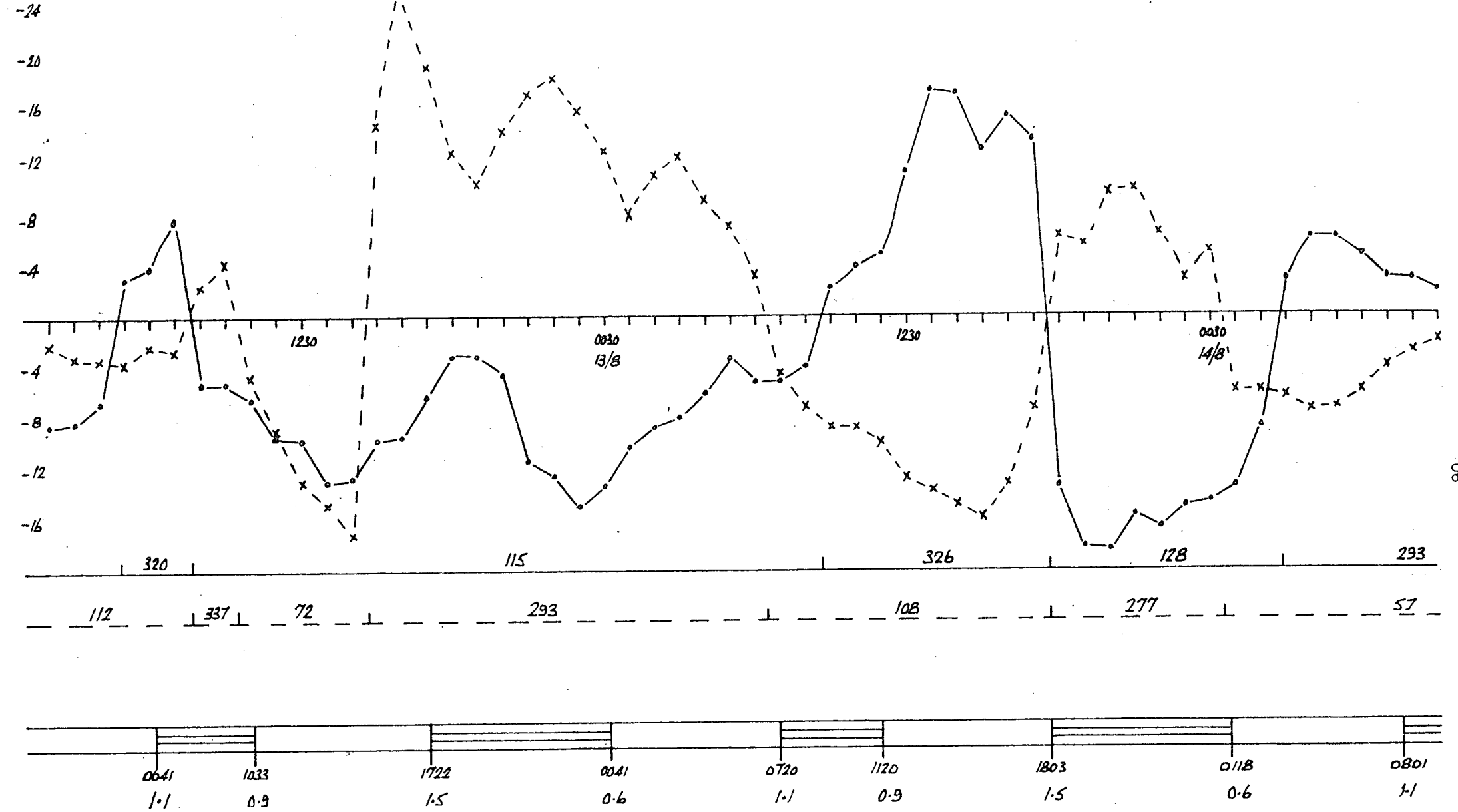


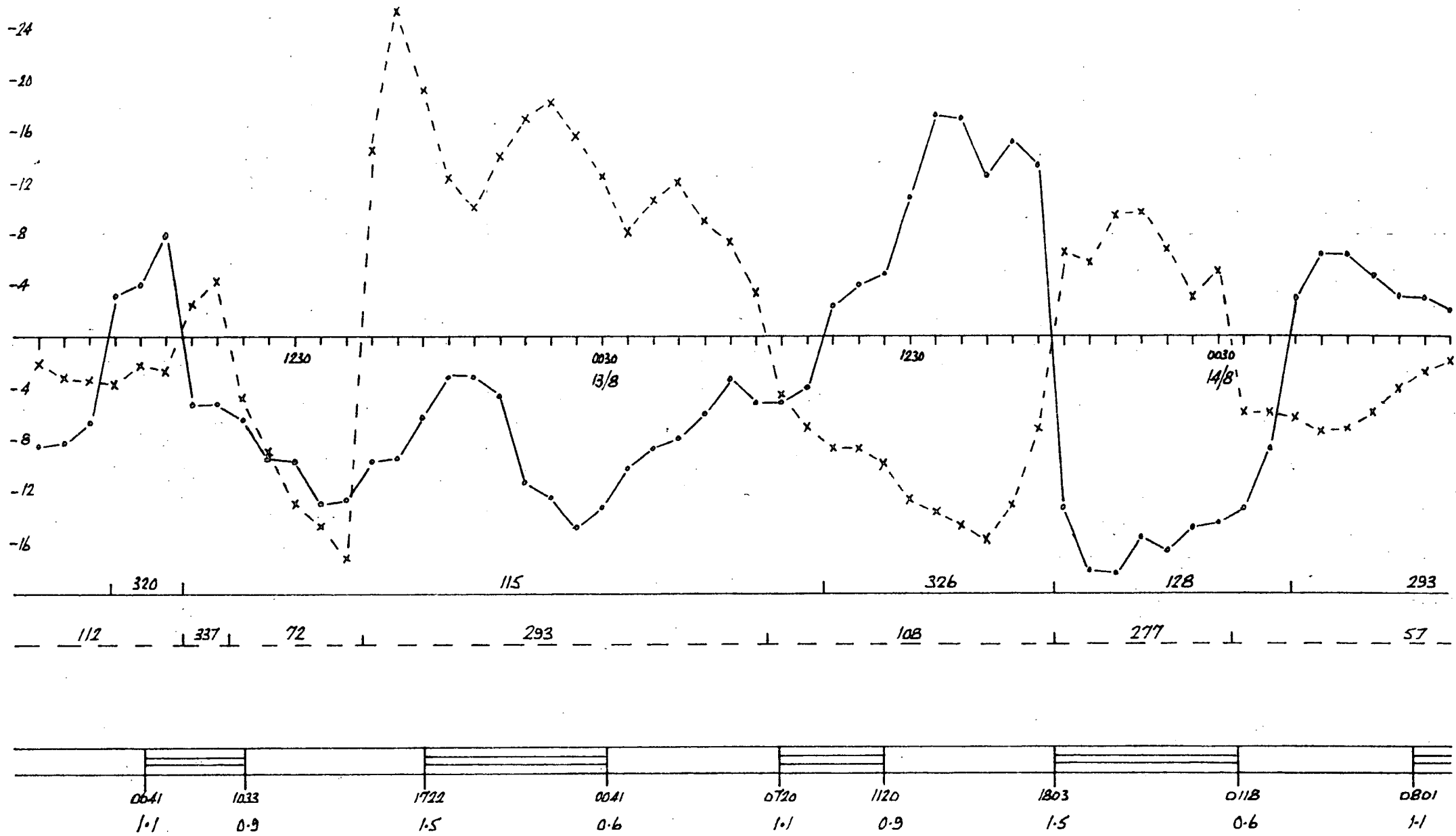
Predicted tide

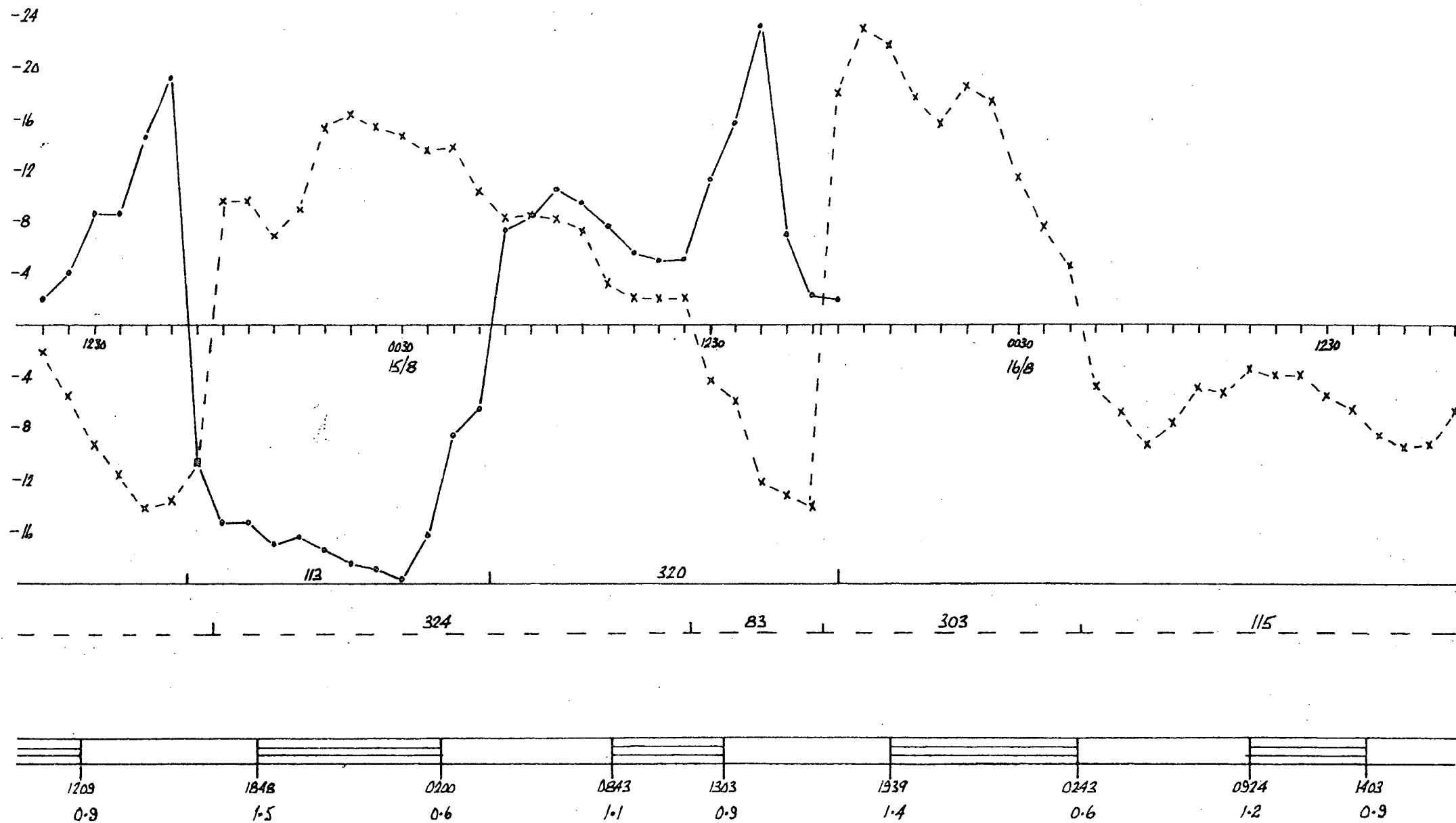












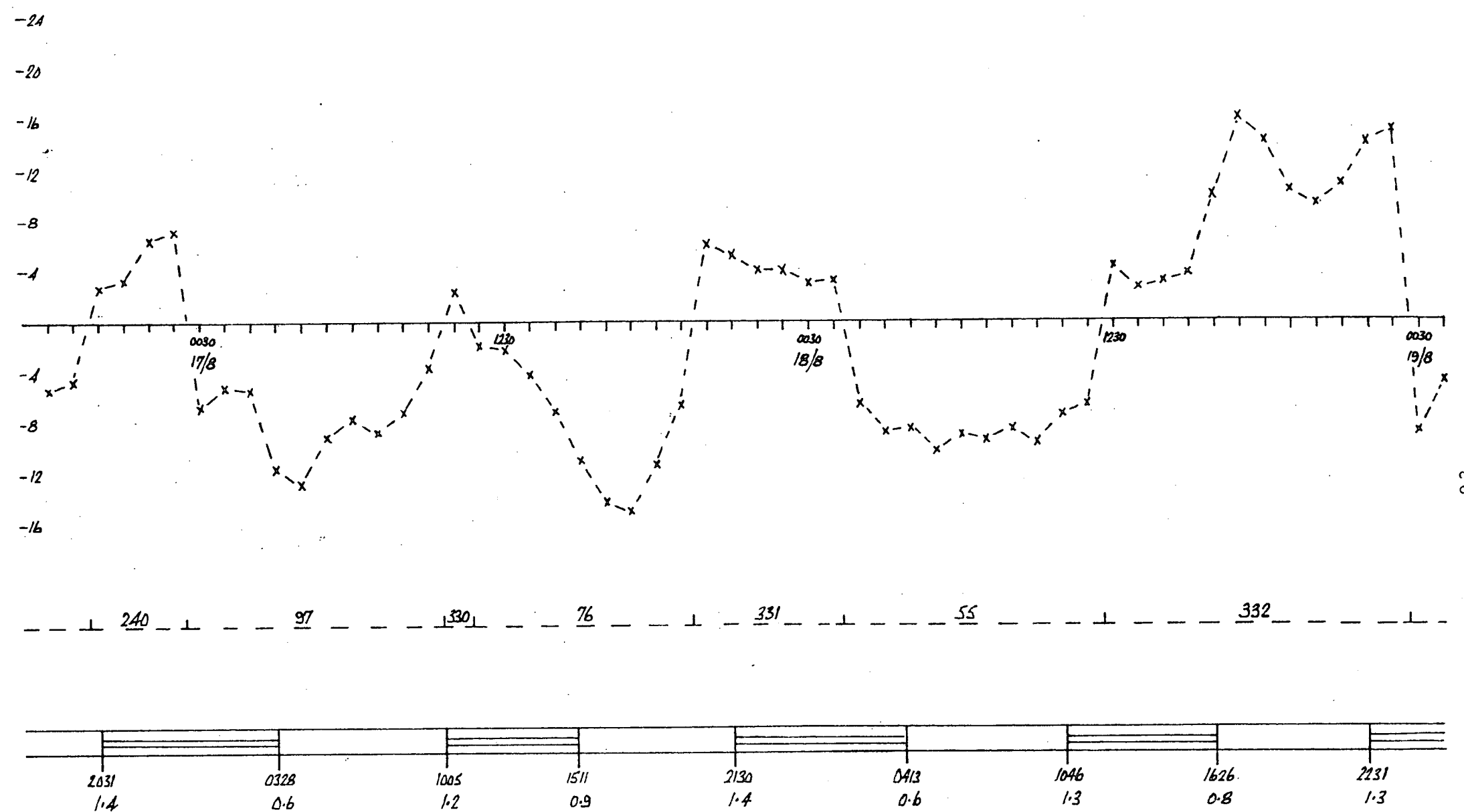
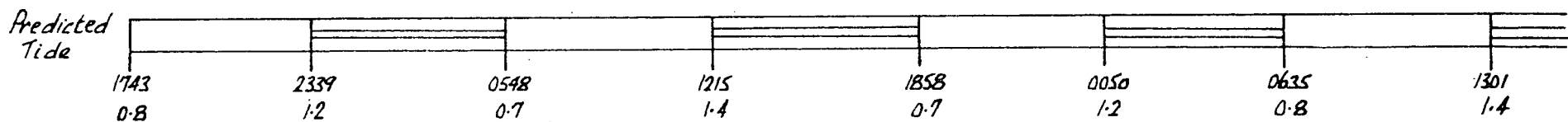
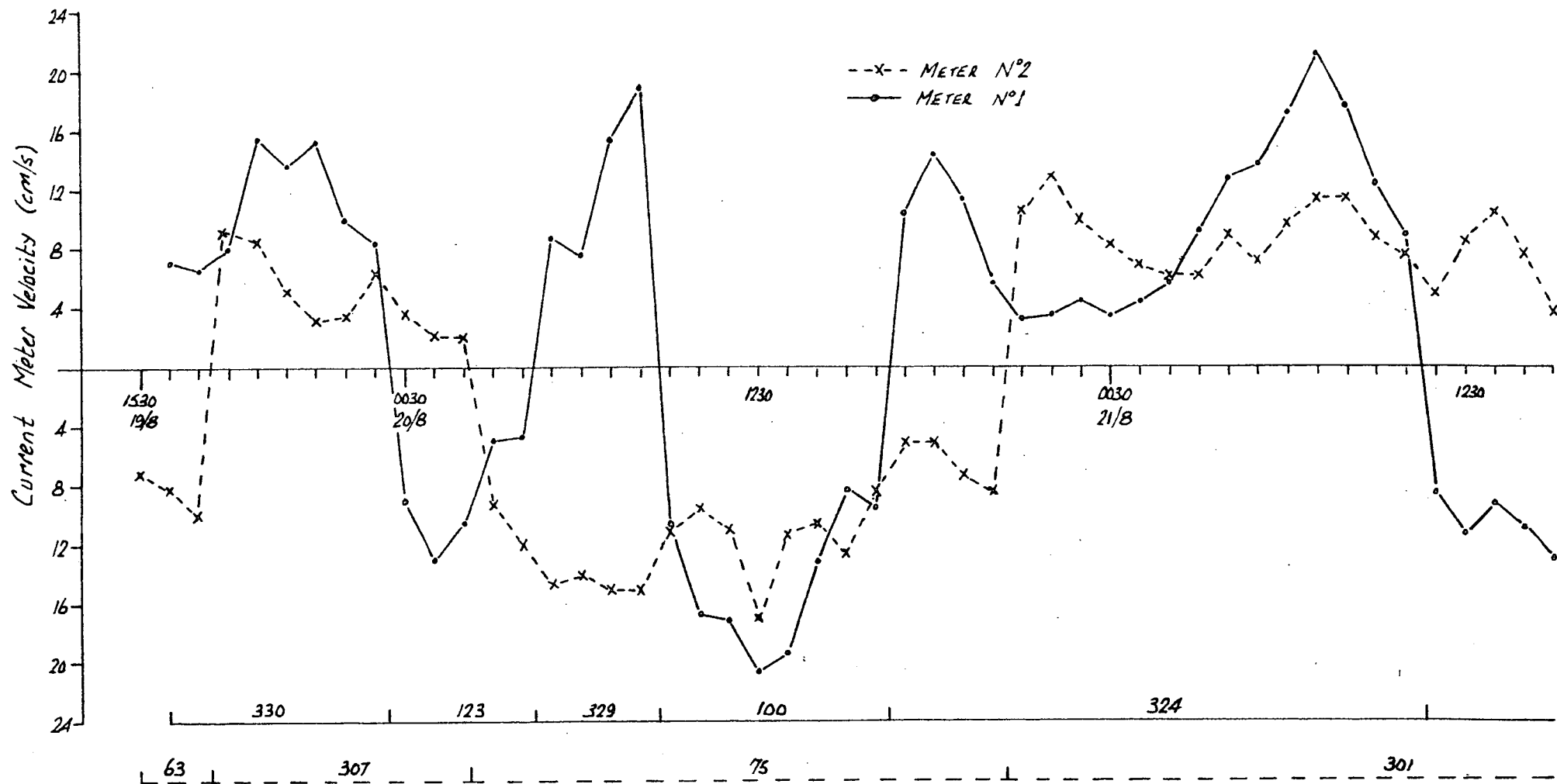
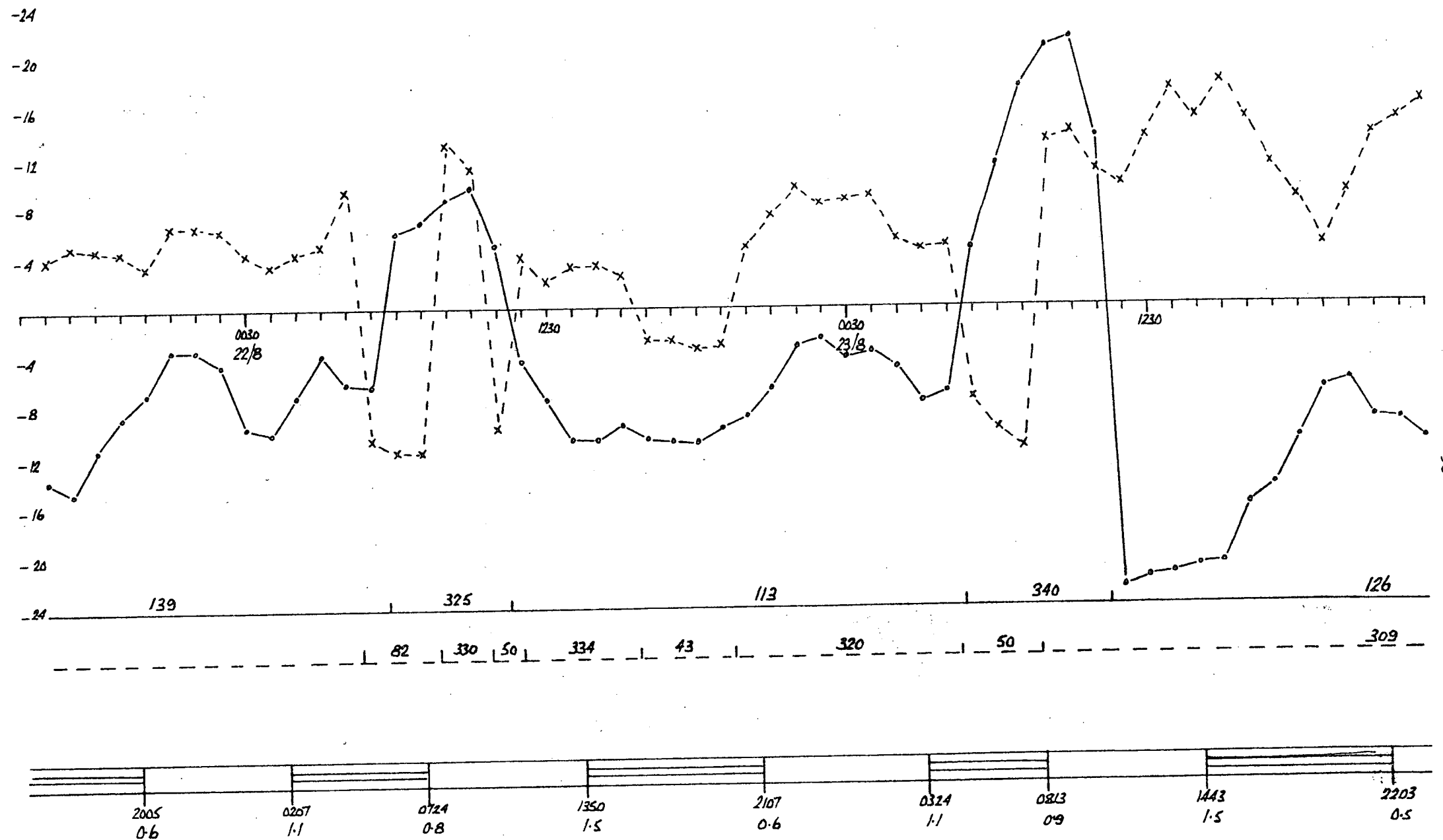
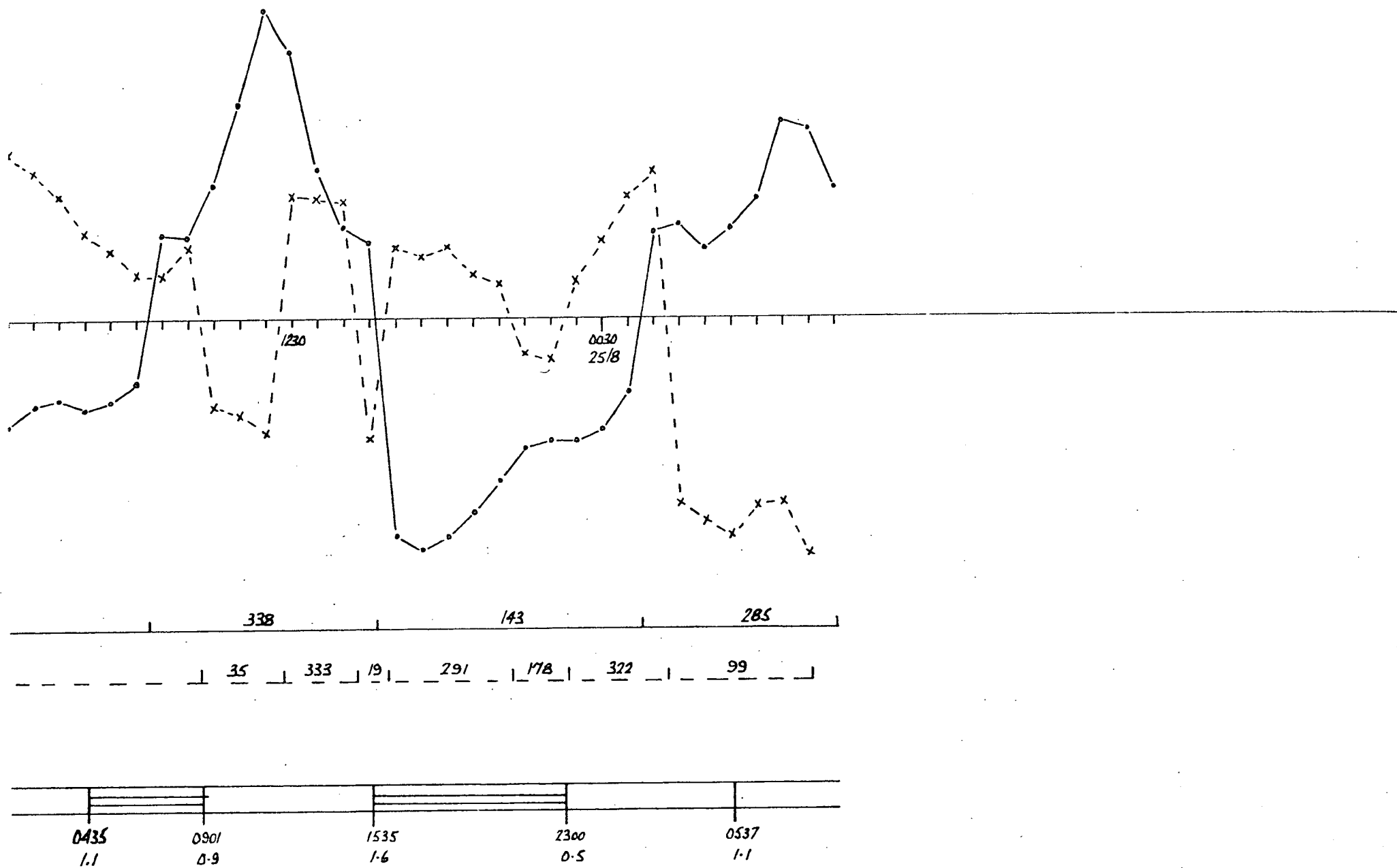


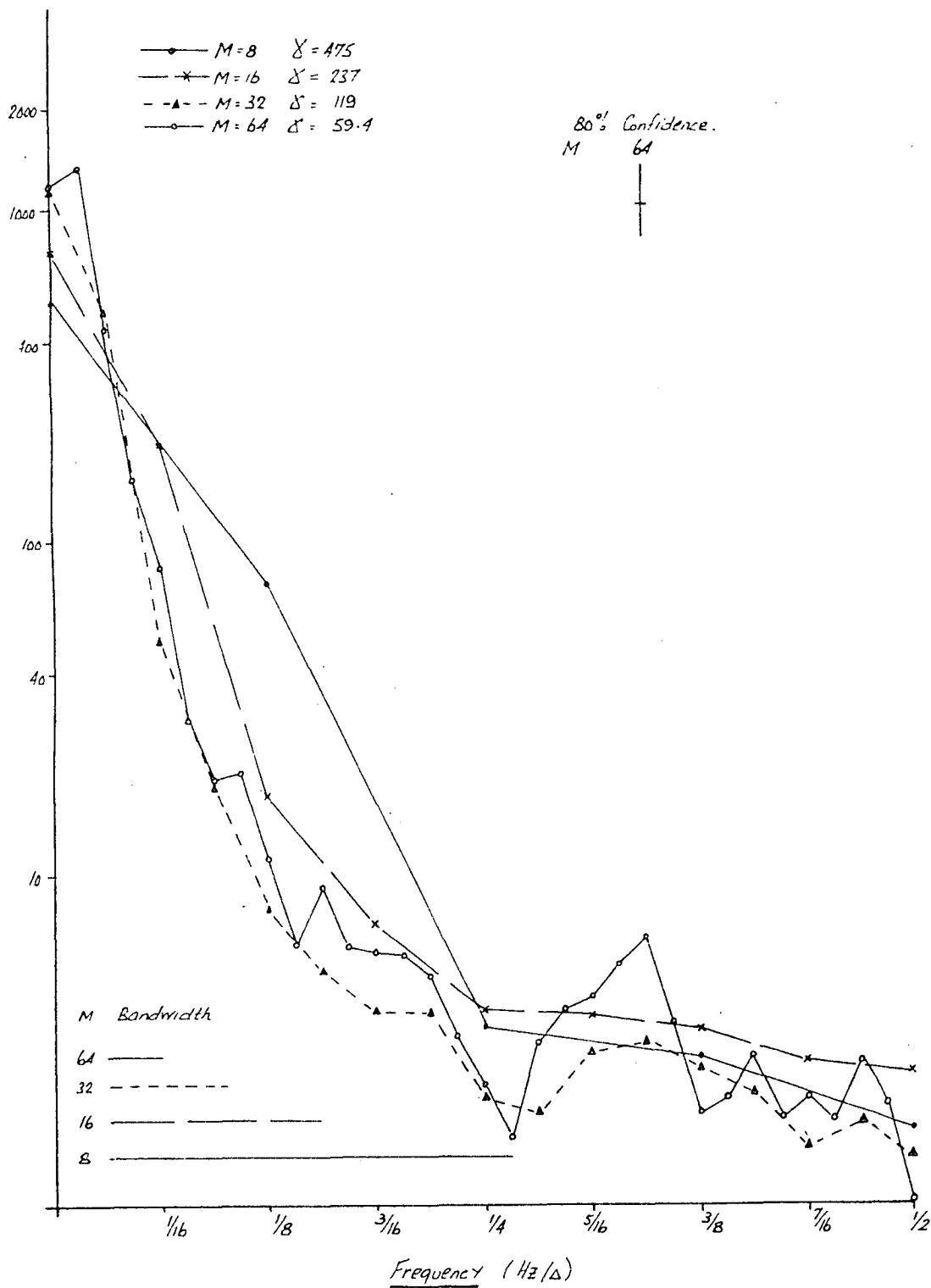
Figure 4.12
Averaged current meter records
19 - 25 Aug.

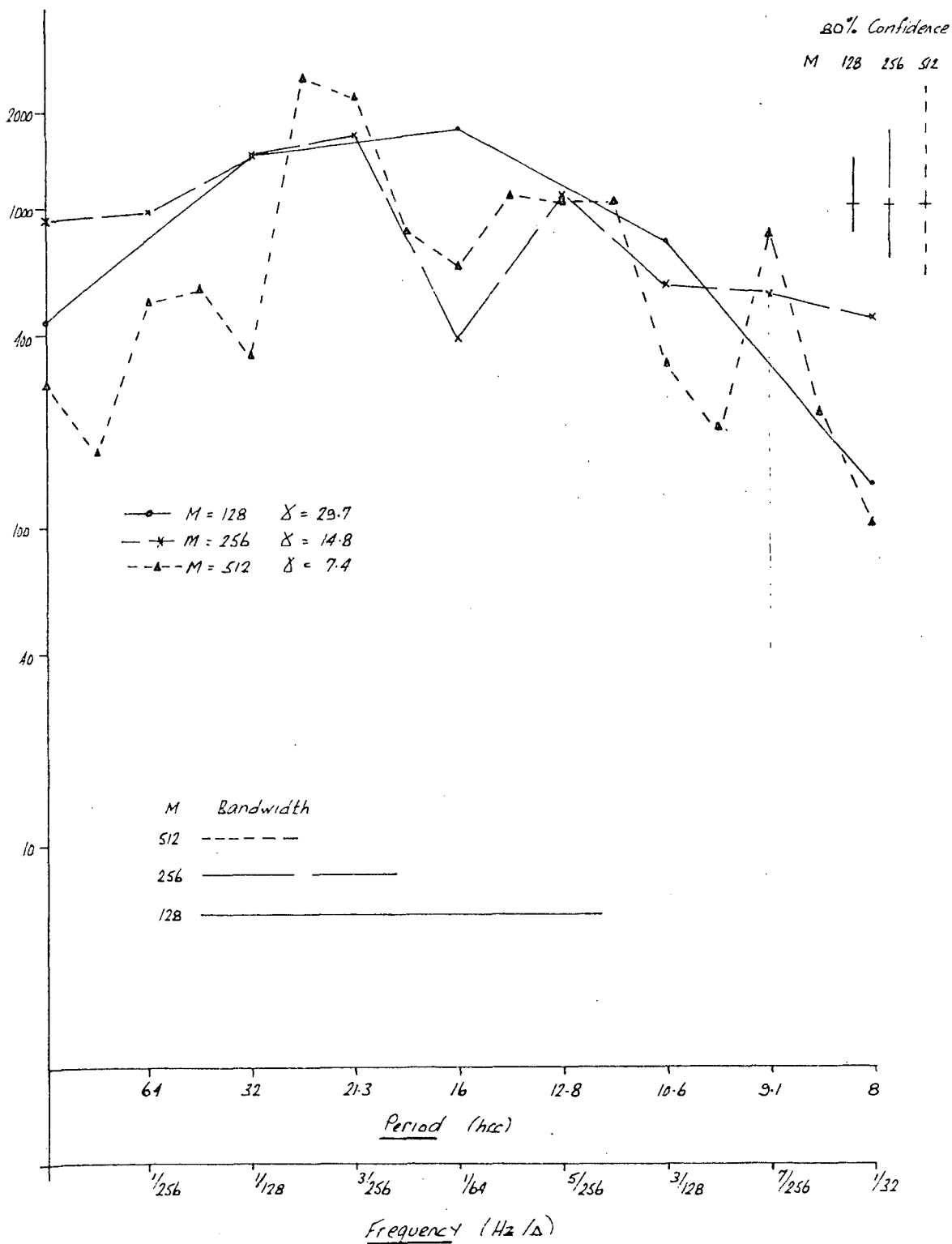
Direction 43° - 143° ————— Direction 285° - 340°

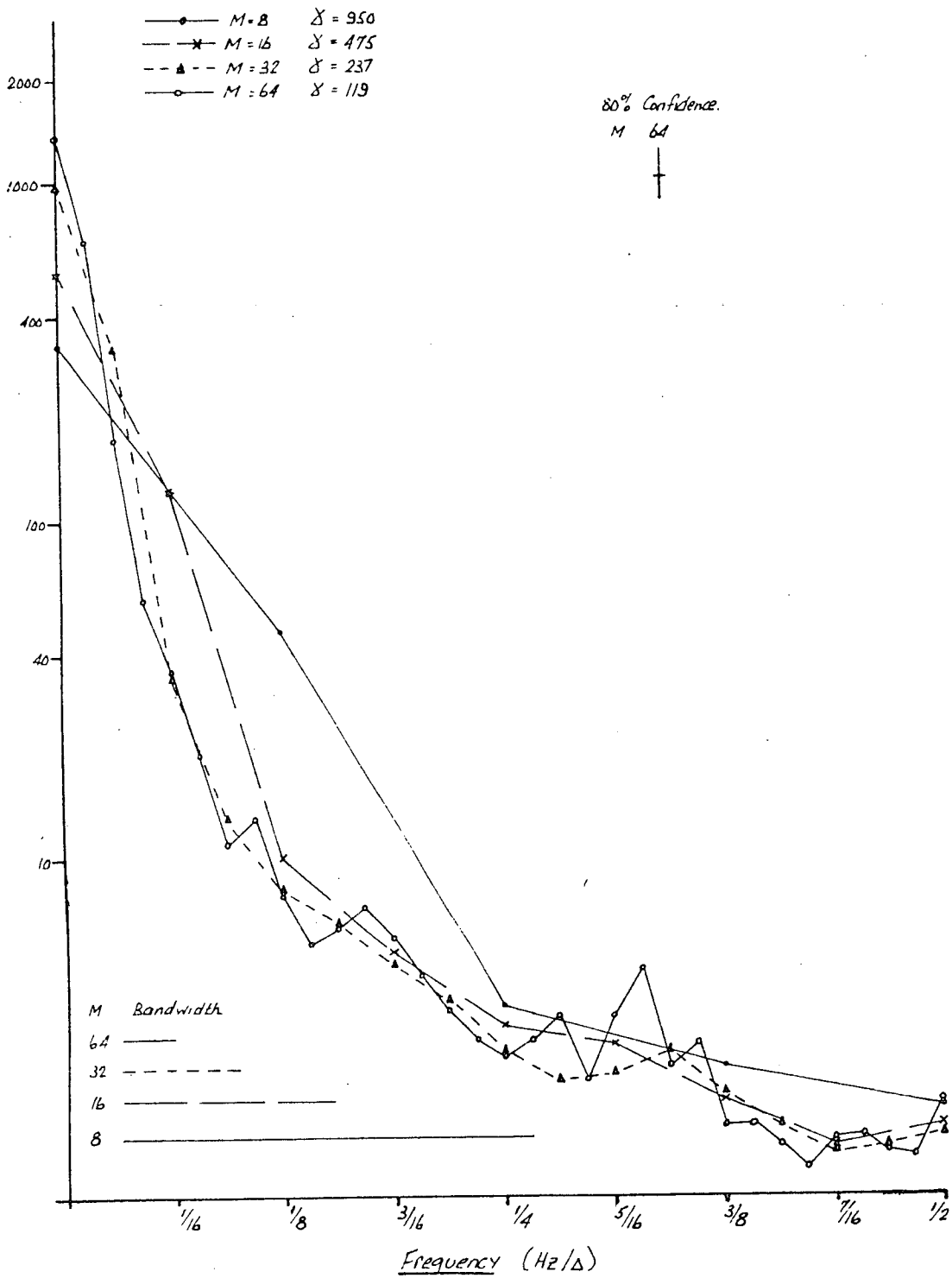


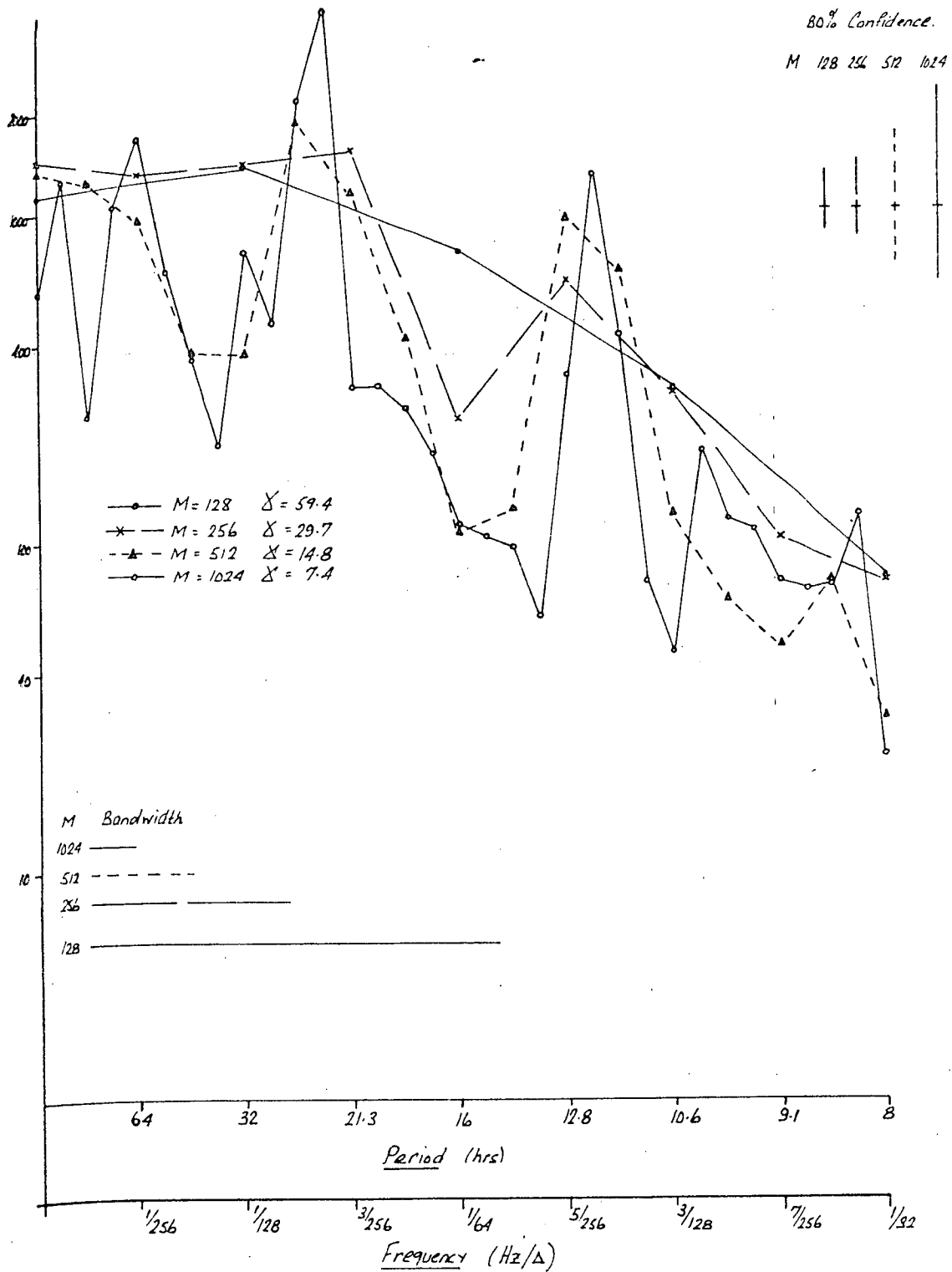


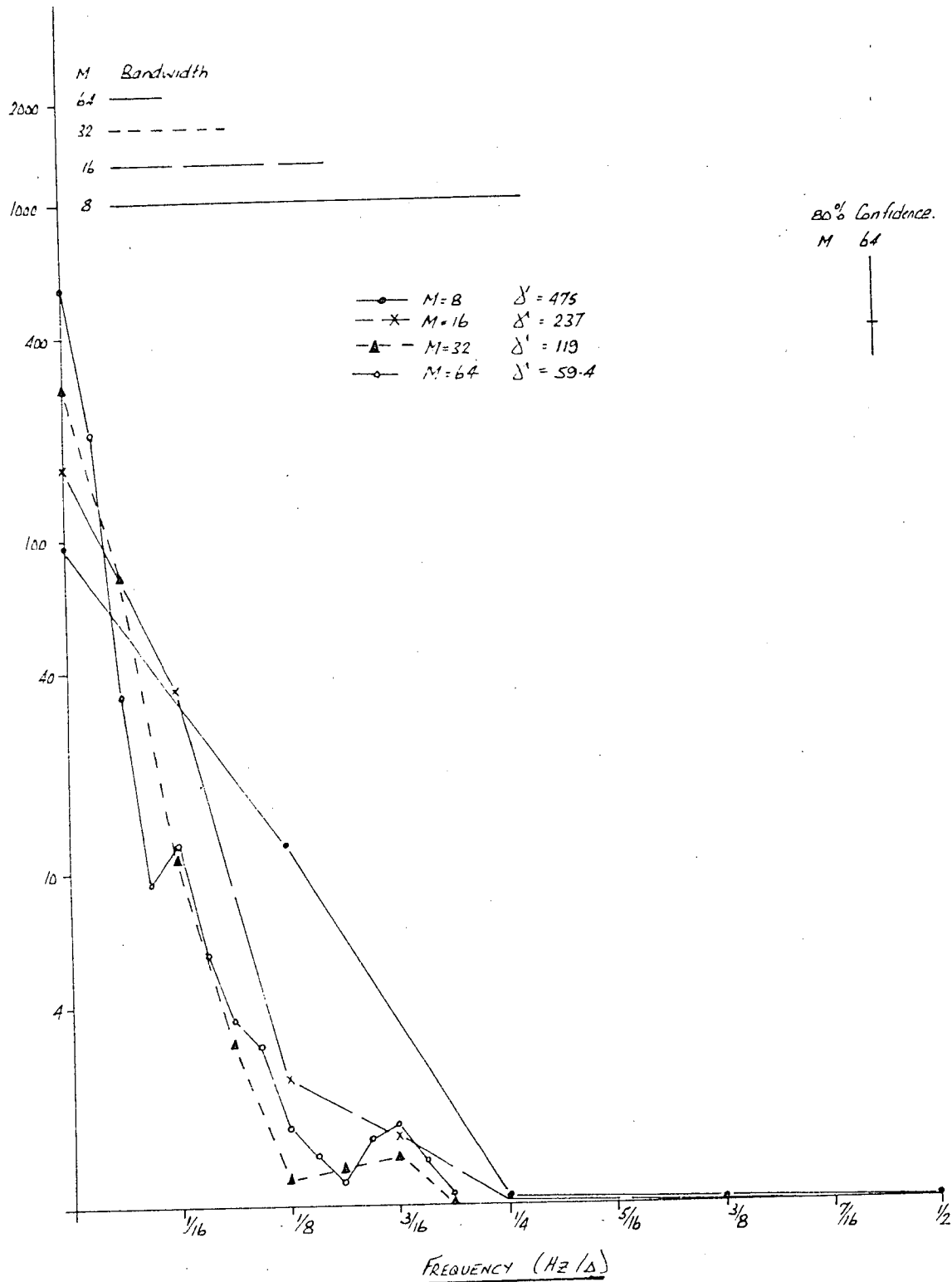


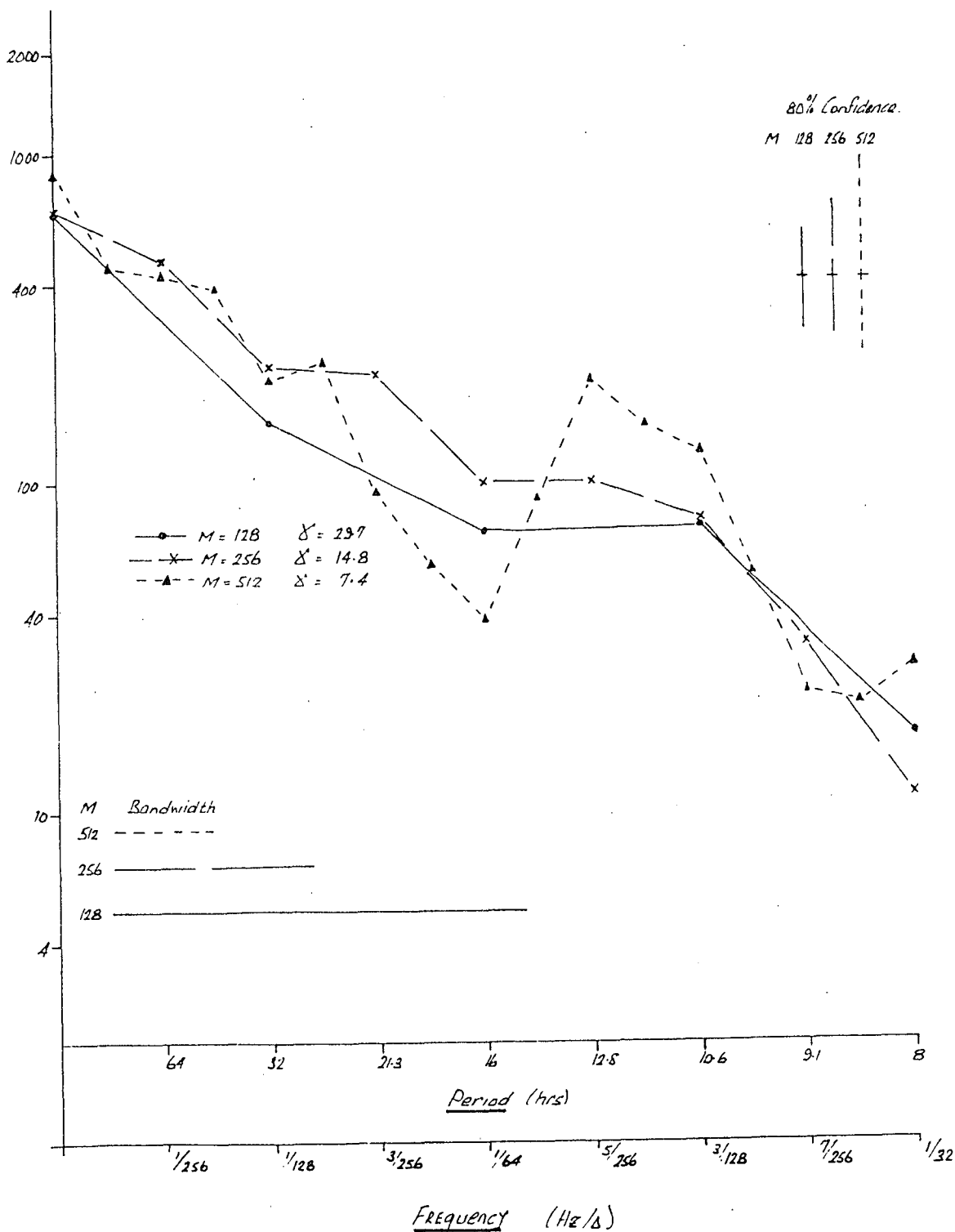












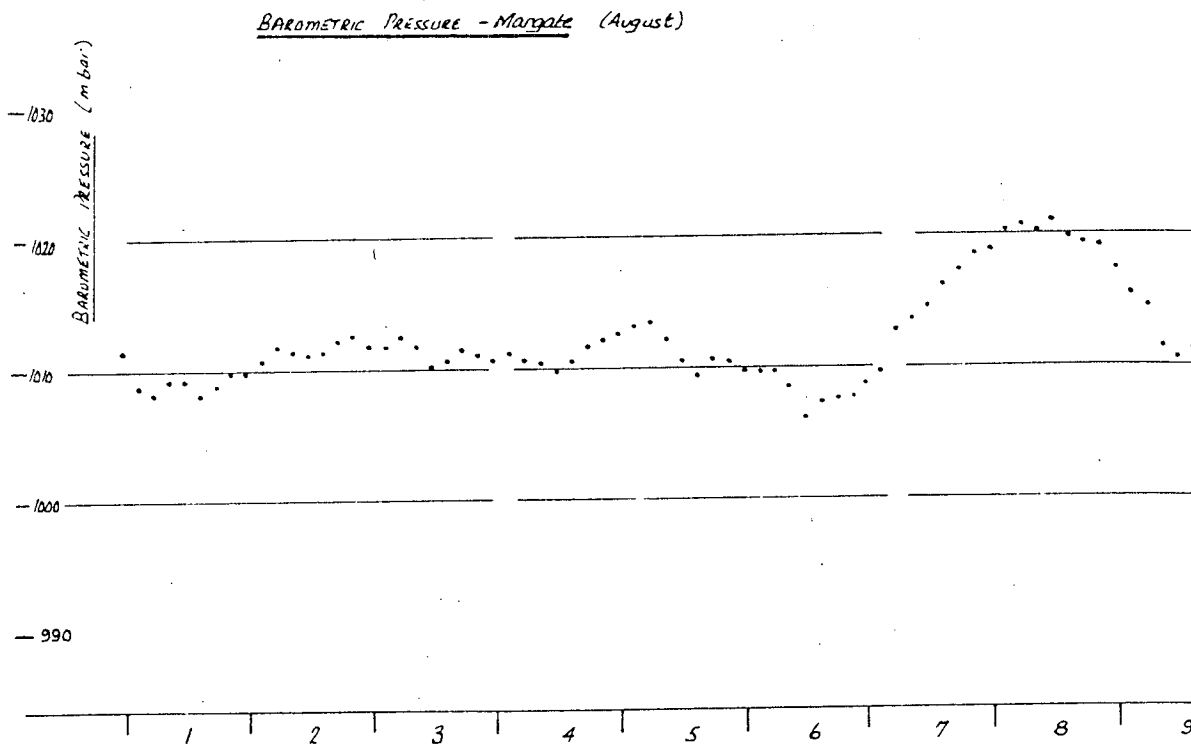
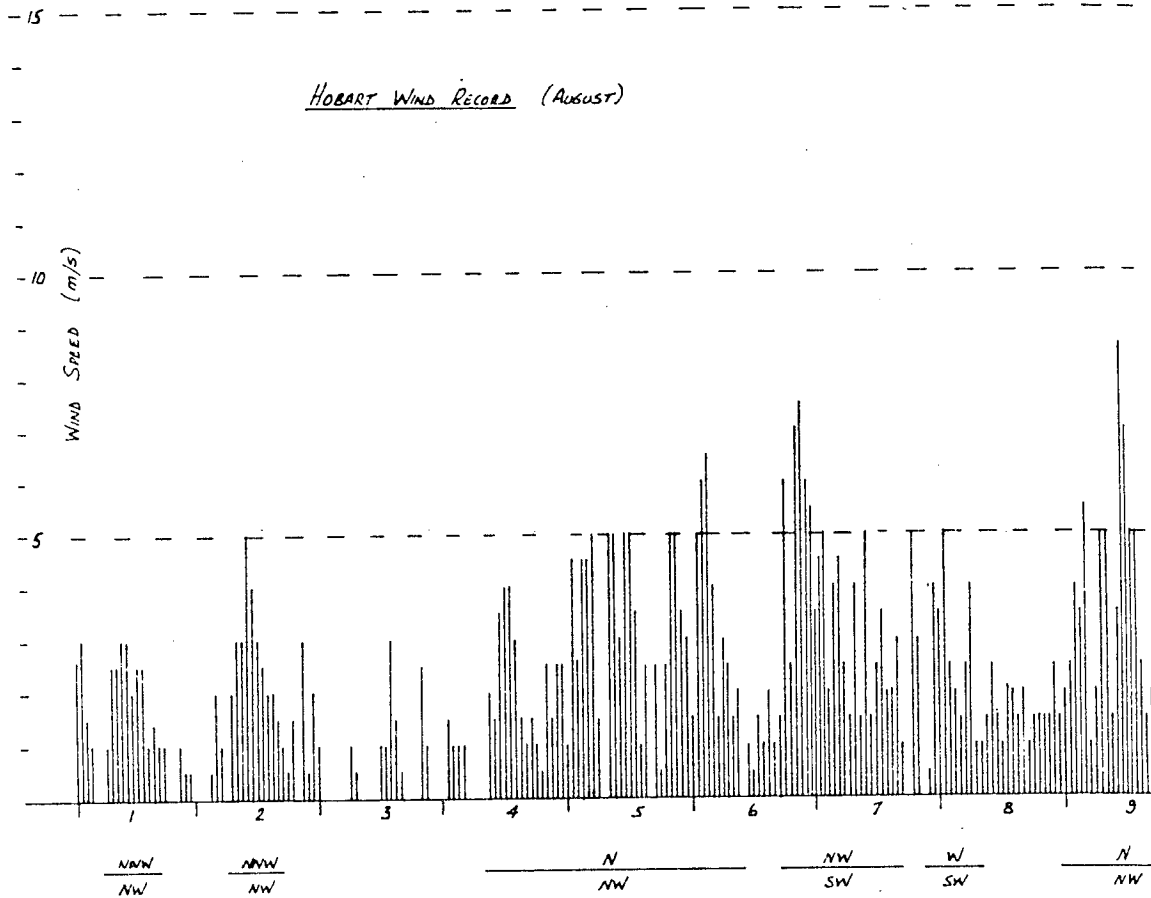
range of 3 to 7 feet, and indicates that the tidal driving mechanism may not be dominant within this zone.

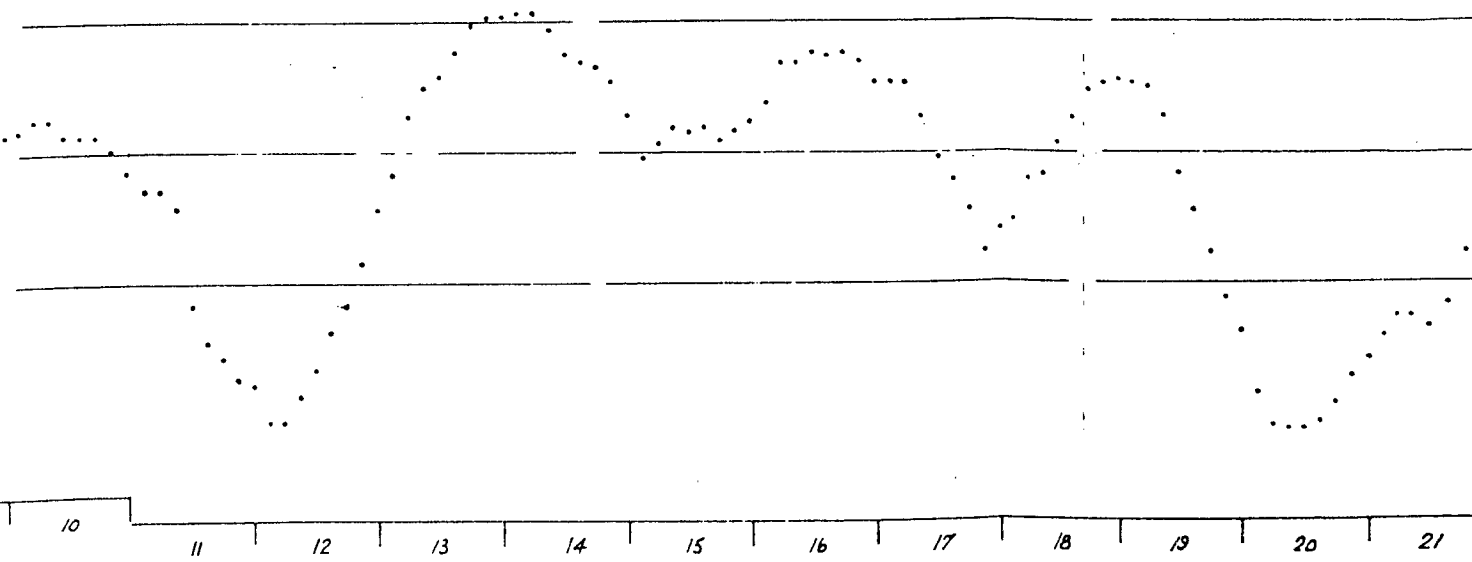
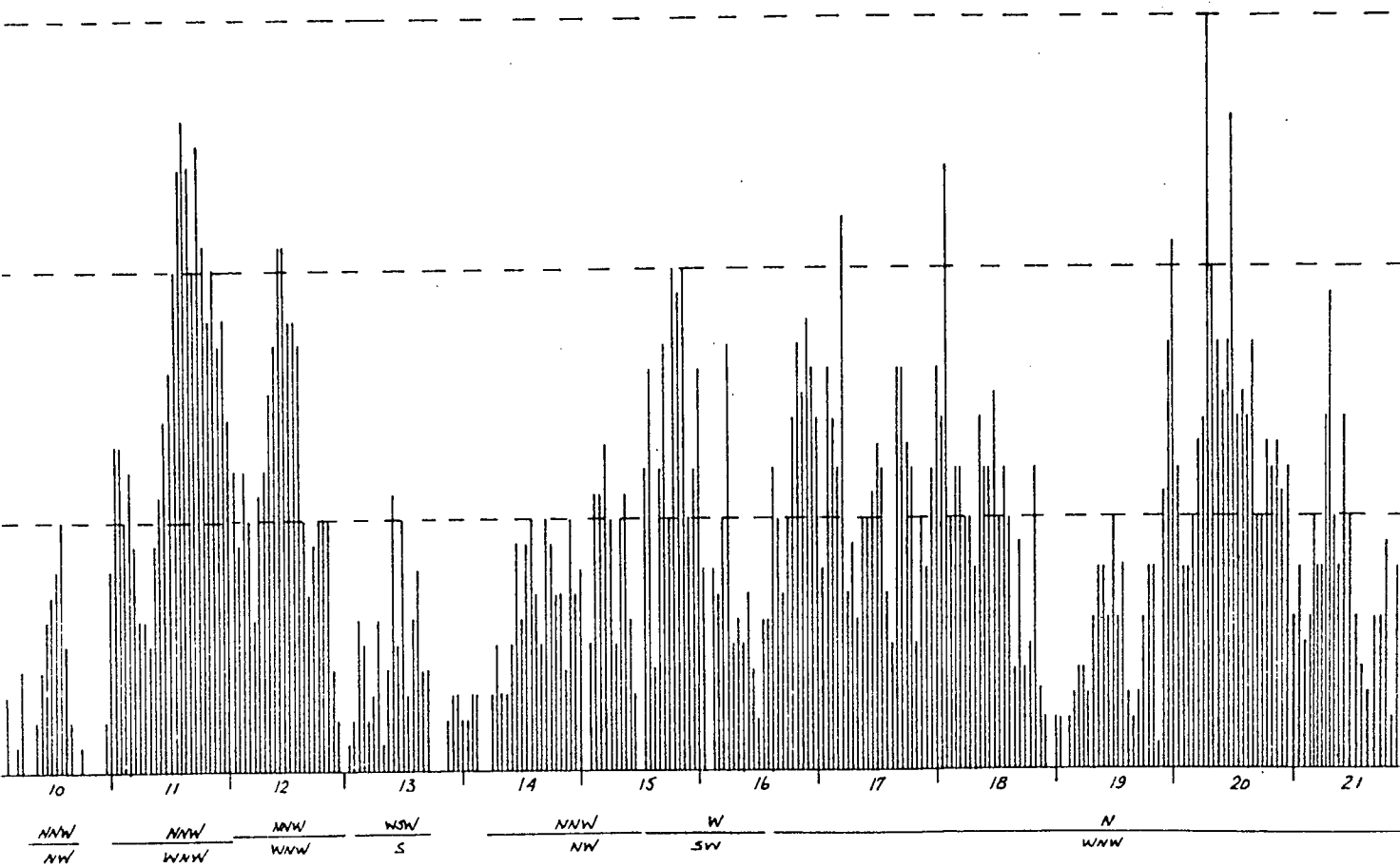
The three current meter records indicate that a range of 21 - 60% of the total energy is contained in the section of the spectrum of periods greater than 24 hours. The longer record length of Meter No. 2 would be more accurate in representing these long period components and this would indicate that the actual proportion of energy in this section of the spectrum could be as much as 50% of the total energy. The significant proportion of energy in this part of the spectrum suggests the influence of meteorological pressure systems. These may be a significant, if not dominant, driving mechanism and much longer records will be required if a more definite evaluation of this mechanism's significance is to be made.

Easton¹⁰ stresses that weather influence in the Hobart zone is severe and predominates in the latter half of the year with the passage of low barometric pressure systems through the area. The work of Karelsky¹¹ indicates that the presence of low pressure cyclones in the area is strongest in the month of August, so that the current meter results of this study could be under a greater meteorological pressure influence than at other times of the year.

The barometric pressure situation at Margate during August is given in Figure 4.16 together with the Hobart wind record. These records show the passage of significant low pressure systems through the area during 11th-12th and 19th-21st. During these periods the tide level at Hobart rose by approximately 0.5 metres above its predicted level (see Table 4.2).

Although the current meter records were not long enough to allow resolution of these long period meteorological components with a great degree of reliability, a spectral analysis of the barometric pressure record was obtained for broad scale correlation. This spectral analysis is shown in Figure 4.17 and indicates that 97% of the energy in the barometric pressure record is contained in periods greater than 48 hours.





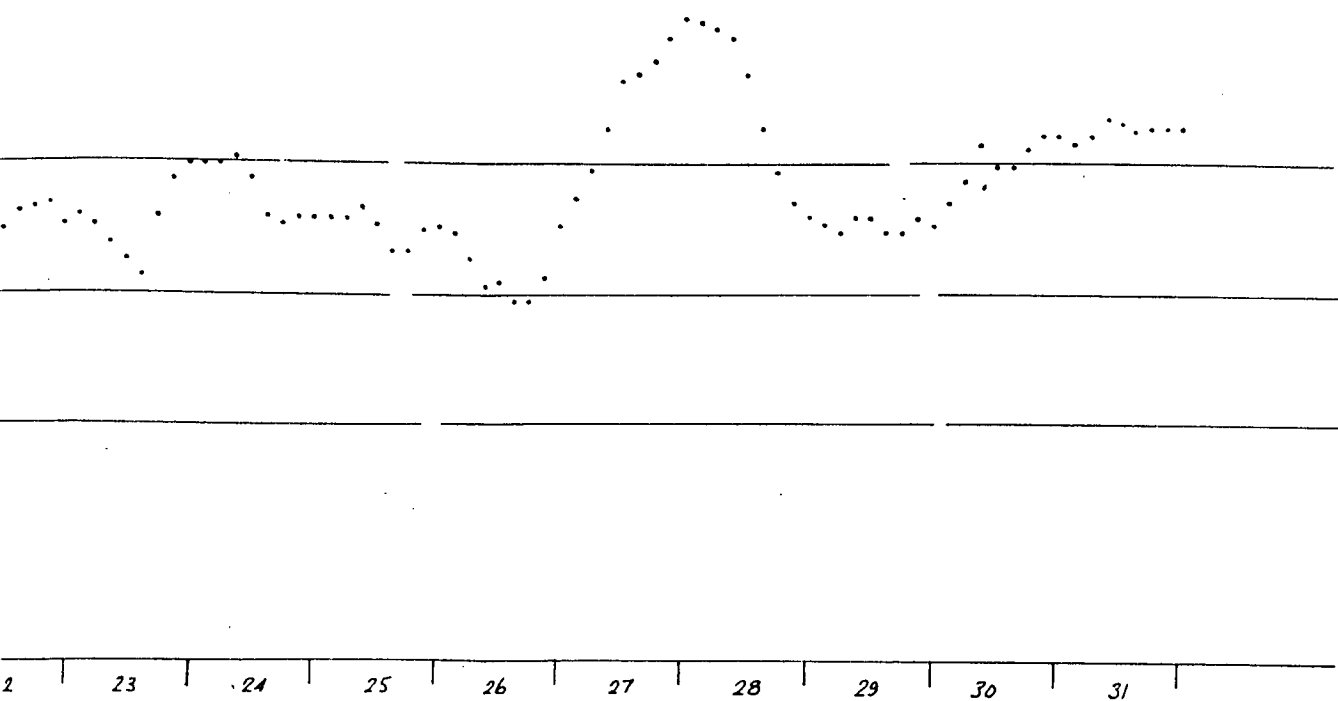
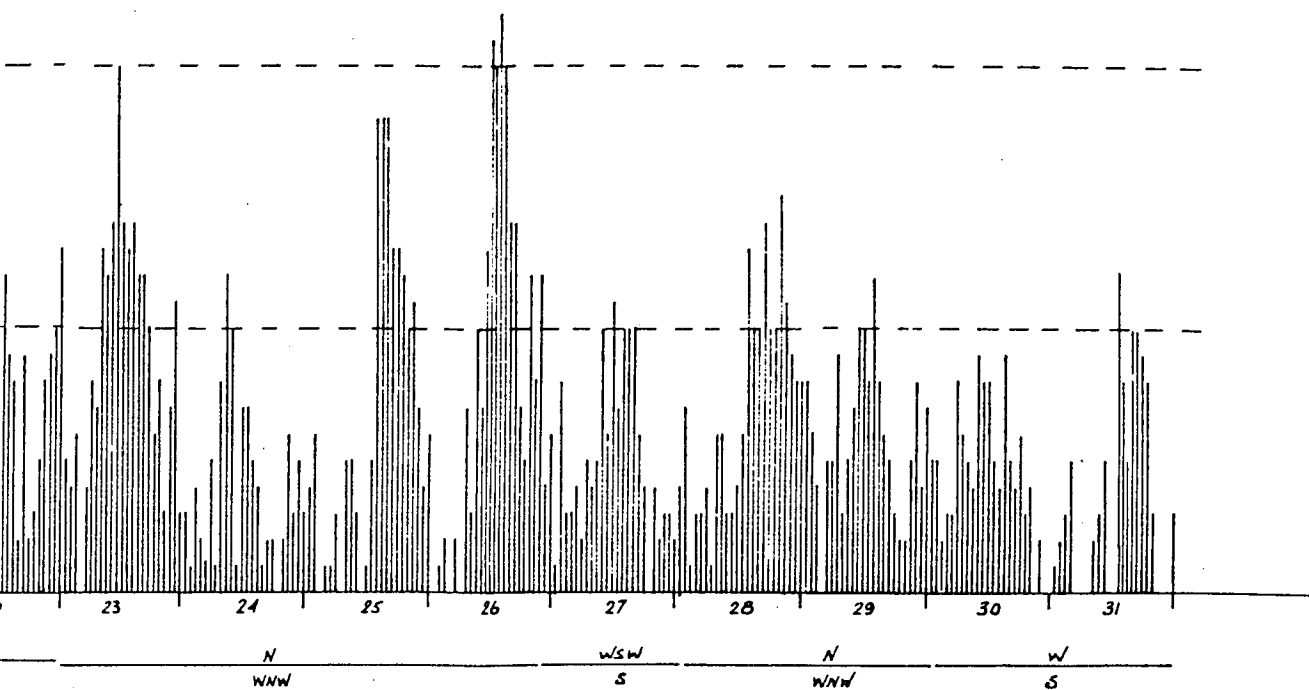


Table 4.2
COMPARISON OF TIDE LEVELS

DATE	PREDICTED		HOBART		DIFFERENCE Predicted level - Hobart level	NORTH WEST BAY	
	TIME (hrs)	LEVEL (m)	TIME (hrs)	LEVEL (m)		TIME (hrs)	LEVEL (m)
31 July	1345	1.0	1345	0.87	+0.13	1400	0.95
	2020	1.5	2020	1.47	+0.03	2030	1.5
1 Aug	0343	0.5	0415	0.4	+0.1	0400	0.5
	1018	1.2	1100	1.2	0.0	1100	1.23
	1458	1.0	1515	0.95	+0.05	1510	1.0
	2116	1.5	2200	1.48	+0.02	2120	1.5
2	0430	0.5	0530	0.49	+0.01	0500	0.55
	1103	1.2	1200	1.26	-0.06	1130	1.275
	1620	0.9	1715	0.82	+0.08	1715	0.85
	2215	1.4	2250	1.3	+0.1	2300	1.35
3	0515	0.6	0530	0.5	+0.1	0530	0.5
	1148	1.3	1200	1.2	+0.1	1215	1.3
	1741	0.9	1815	0.8	+0.1	1815	0.85
	2313	1.3	0015	1.23	+0.07	0015	1.3
4	0556	0.7	0630	0.67	+0.03	0645	0.68
	1230	1.3	1300	1.37	-0.07	1315	1.35
	1854	0.9	1930	0.85	+0.05	2000	0.90
5	0013	1.2	0115	1.2	0.0	0130	1.22
	0633	0.7	0730	0.8	-0.1	0715	0.82
	1311	1.3	-	-	-	1400	1.32
	2000	0.8	-	-	-	2115	0.85
6	0116	1.1	-	-	-	0215	1.2
	0707	0.8	-	-	-	0715	0.85
	1350	1.4	-	-	-	1450	1.4
	2054	0.8	-	-	-	2100	0.8
7	0222	1.1	-	-	-	0300	1.05
	0737	0.8	-	-	-	0745	0.85
	1428	1.4	1500	1.3	+0.1		
	2143	0.8	2200	0.62	+0.18		
8	0326	1.0	0330	0.95	+0.05		
	0807	0.9	0900	0.75	+0.15		
	1501	1.4	1530	1.25	+0.15		
	2224	0.7	2315	0.5	+0.2		
9	0424	1.0	0430	0.88	+0.12		
	0839	0.9	0900	0.72	+0.18		
	1535	1.4	1615	1.35	+0.05		
	2300	0.7	2350	0.6	+0.1		
10	0515	1.0	0500	1.0	+0.0		
	0913	0.9	0945	0.85	+0.05		
	1609	1.4	1615	1.4	0.0		
	2331	0.7	0045	0.6	+0.1		
11	0558	1.0	0630	1.0	0.0		
	0952	0.9	0950	0.85	+0.05		
	1643	1.4	1730	1.85	-0.45		
12	0005	0.6	0045	1.05	-0.45		
	0641	1.1	0700	1.57	-0.47		
	1033	0.9	1030	1.37	-0.47		
	1722	1.5	1830	1.97	-0.47		
13	0041	0.6	0200	1.02	-0.42		
	0720	1.1	0800	1.42	-0.32		
	1120	0.9	1200	1.22	-0.32		
	1803	1.5	1900	1.7	-0.2		
14	0118	0.6	0200	0.74	-0.14		
	0801	1.1	0900	1.25	-0.15		
	1209	0.9	1300	1.07	-0.17		
	1848	1.5	1950	1.66	-0.16		
15	0200	0.6	0250	0.8	-0.2		
	0843	1.1	0900	1.4	-0.3		
	1303	0.9	1300	1.5	-0.6		
	1939	1.4	2000	1.75	-0.35		
16	0243	0.6	0300	0.9	-0.3		
	0924	1.2	0930	1.45	-0.25		
	1403	0.9	1400	1.12	-0.22		
	2031	1.4	2030	1.57	-0.17		
17	0328	0.6	0400	0.8	-0.2		
	1005	1.2	1030	1.4	-0.2		
	1511	0.9	1530	1.12	-0.22		
	2130	1.4	2200	1.6	-0.2		
18	0413	0.6	0430	0.87	-0.27		
	1046	1.3	1100	1.6	-0.3		
	1626	0.8	1700	1.15	-0.35		
	2231	1.3	2300	1.51	-0.21		
19	0500	0.7	0530	0.82	-0.12		
	1130	1.3	1200	1.47	-0.17		
	1743	0.8	1800	1.0	-0.2		
	2339	1.2	0030	1.5	-0.3		
20	0548	0.7	0600	1.0	-0.3		
	1215	1.4	1200	1.8	-0.4		
	1858	0.7	1830	1.1	-0.4		
21	0050	1.2	0100	1.6	-0.4		
	0635	0.8	0650	1.7	-0.4		
	1301	1.4	1330	1.8	-0.4		
	2005	0.6	2030	0.97	-0.37		
22	0207	1.1	0230	1.43	-0.33		
	0724	0.8	0800	1.05	-0.25		
	1350	1.5	1400	1.65	-0.15		
	2107	0.6	2130	0.7	-0.1		
23	0324	1.1	0330	1.3	-0.2		
	0813	0.9	0830	1.03	-0.13		
	1443	1.5	1500	1.8	-0.3		
	2203	0.5	2230	0.77	-0.27		
24	0435	1.1	0430	1.4	-0.3		
	0901	0.9	0945	1.1	-0.2		
	1535	1.6	1540	1.88	-0.28		
	2300	0.5	2300	0.75	-0.25		
25	0537	1.1	0530	1.42	-0.32		
	0954	0.9	0950	1.11	-0.21		
	1630	1.6	1630	1.85	-0.25		
	2350	0.5	2350	0.7	-0.2		
26	0630	1.1	0630	1.45	-0.35		
	1048	0.9	1030	1.16	-0.26		
	1724	1.6	1800	1.96	-0.36		
27	0041	0.5	0050	0.72	-0.22		
	0716	1.1	0715	1.35	-0.25		
	1145	0.9	1100	1.00	-0.1		
	1822	1.5	1830	1.65	-0.15		
28	0130	0.5	0200	0.53	-0.03		
	0800	1.2	0800	1.25	-0.05		
	1245	0.9	1300	0.91	-0.01		
	1918	1.5	1930	1.58	-0.08		
29	0216	0.6	0215	0.64	-0.04		
	0843	1.2	0850	1.4	-0.2		
	1348	0.8	1330	1.05	-0.25		
	2015	1.4	2100	1.7	-0.3		
30	0301	0.6	0330	0.86	-0.26		
	0924	1.2	0930	1.5	-0.3		
	1450	0.8	1550	1.05	-0.25		
	2113	1.3	2140	1.54	-0.24		
31	0345	0.7	0430	0.82	-0.12		

the tide records for North West Bay during this period were disrupted by recorder malfunctions and the data obtained was not considered reliable enough for incorporation in this table

— * — $M=32$ $\delta = 29.7$
 — o — $M=64$ $\delta = 15$
 - - Δ - - $M=128$ $\delta = 7.5$

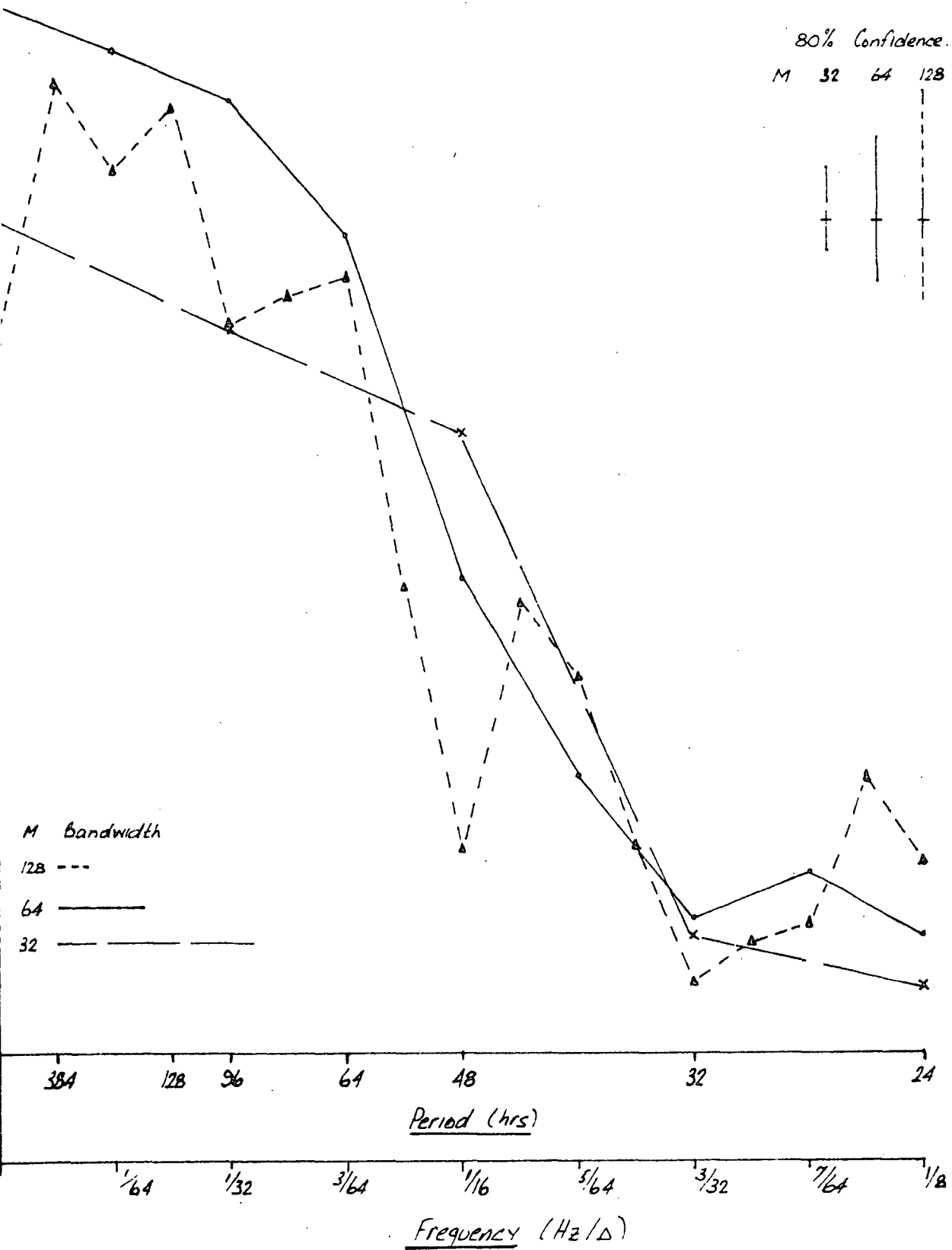


Figure 4.17

Spectral estimates of barometric pressure

Another feature of the current meter records is the measurement of consistently high velocities up to 30 cm/s at the two locations across the entrance of North West Bay. As can be seen from Figure 2.1, North West Bay is coupled to the northern end of the D'Entrecasteaux Channel and is isolated from the direct influence of Storm Bay and the Tasman Sea by Bruny Island. This channel is approximately 50 km long and the variations in tidal times and levels at its boundaries, together with differential meteorological pressure gradients, could produce large and complex flows. This factor is important in considering the circulation within North West Bay and some evidence is given in Section 4.3 to show that the circulation within North West Bay is 'pumped by the dominant flow regime in the channel.' This geographical situation can be considered as a mechanism whereby the actual driving mechanisms experienced in North West Bay are a secondary, or couple, response to the boundary conditions of the D'Entrecasteaux Channel. Before more detailed information can be obtained for North West Bay, future studies should be aimed at determining the conditions of flow within the D'Entrecasteaux Channel. In this regard it should be noted that the channel itself may act somewhat like a low pass filter to remove shorter period motions.

4.1.3 Summary

From the data obtained in this study the major conclusions that can be drawn on the driving mechanisms are:

- . The influence of wind-stress is limited to the surface layers of the water body and its predominant influence is to act as a transient mixing mechanism.
- . Tides are a significant driving mechanism with the diurnal component more dominant than the semi-diurnal component.

- . Atmospheric pressure systems appear to be a significant driving mechanism and may dominate other mechanisms particularly in the winter months.
- . The D'Entrecasteaux Channel may act as a coupling and filtering system between North West Bay and the boundary states of the channel. These boundary states are within themselves a reflection of tidal, meteorological and other conditions over a wider area.

1.2 Water Exchanges

Some aspects of the exchange between the bay and its adjacent waters can be inferred from the salinity and temperature measurements made during the study.

This section of the report discusses some aspects of the salinity-temperature structure of the bay and the changes that occur. Some attempt is made to estimate the rates of exchange from a consideration of the fresh water content of the bay, and some evidence is presented for the influence of adjacent estuarine waters.

Occasionally reference to detailed climatological data is made. This could not be conveniently presented in the text, and is provided in Appendix B.

4.2.1 Salinity-temperature characteristics

The bulk of the salinity and temperature information gathered during this study is tabulated in Appendix C. It was found that measurements taken along transects BB'B" and CC'C" (see Figure 4.18) were generally representative of the changes occurring throughout the study area. Thus only measurements taken along these transects have been presented as cross-sectional profiles of salinity, temperature and density (see Figure 4.19).

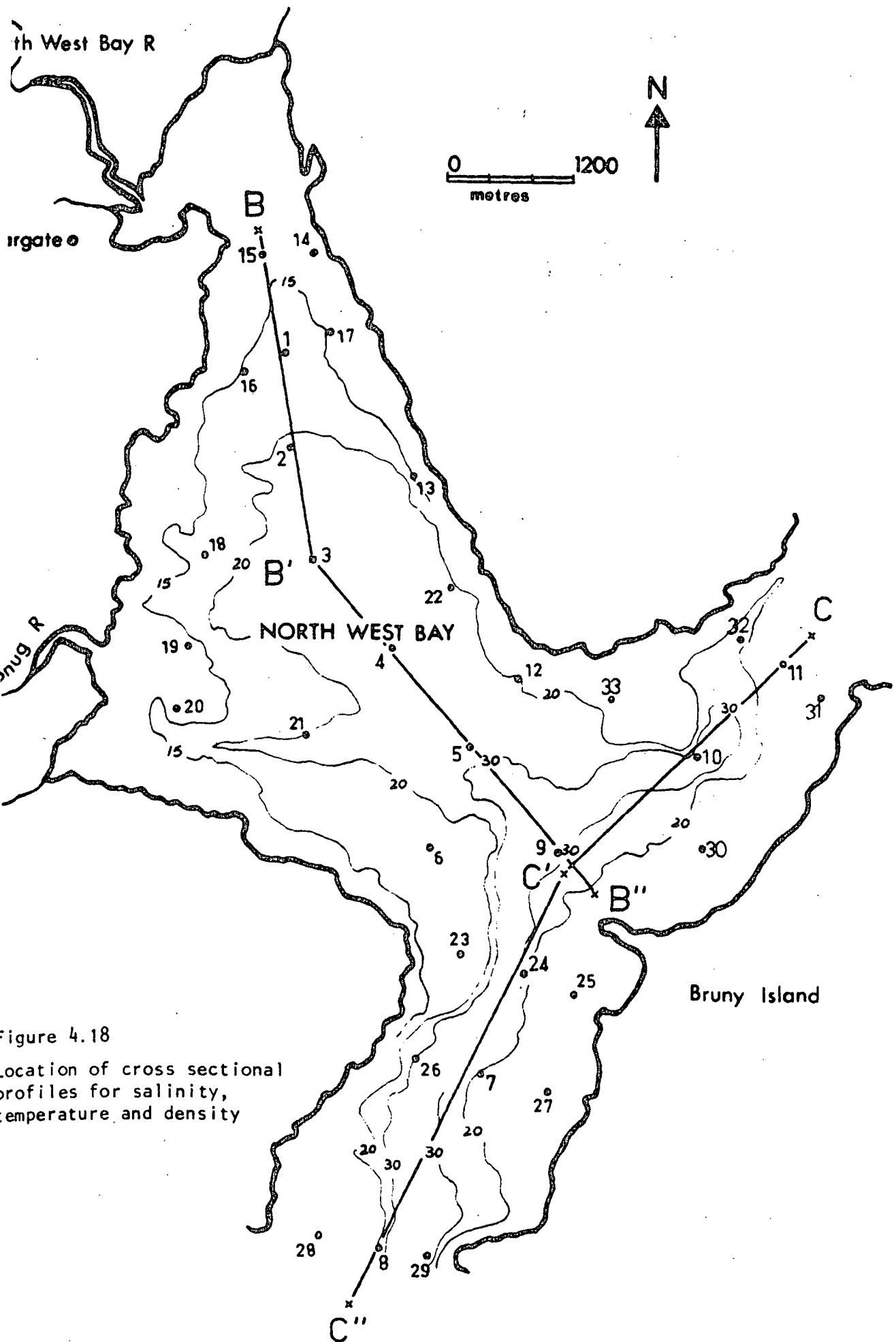


Figure 4.18
Location of cross sectional
profiles for salinity,
temperature and density

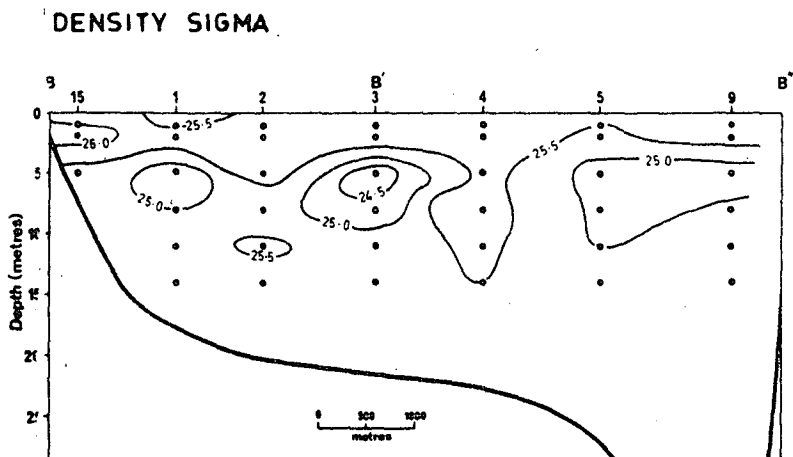
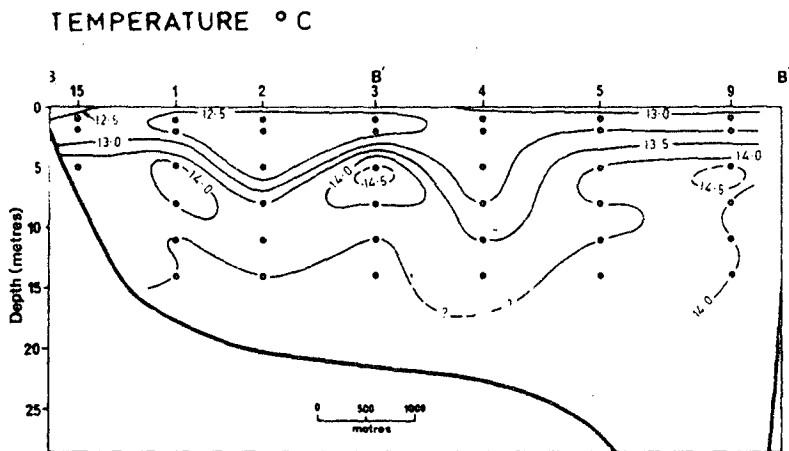
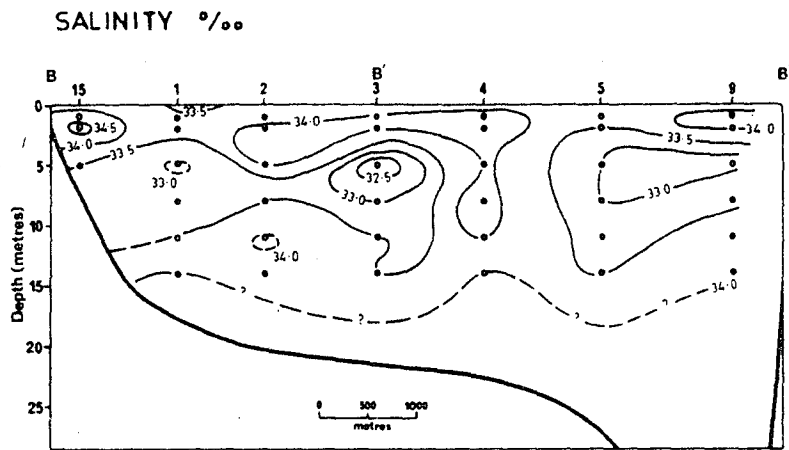
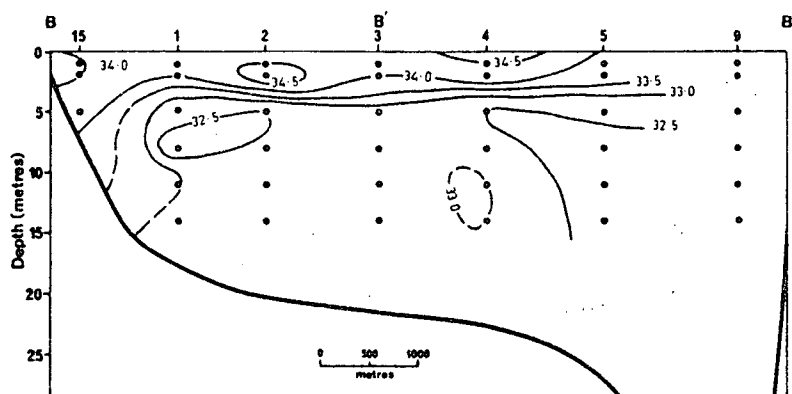
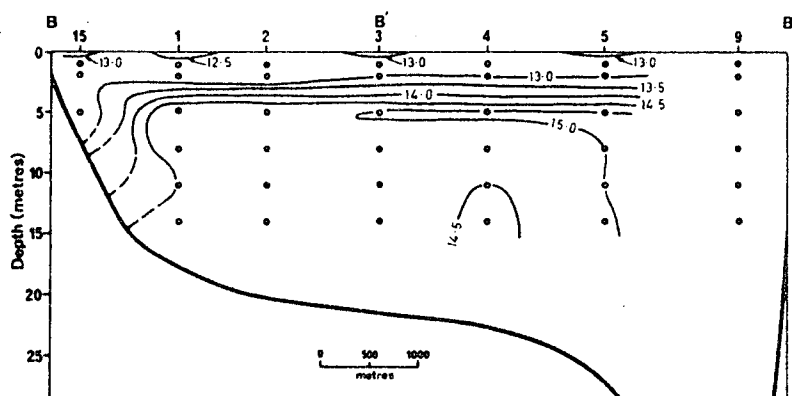


FIGURE 4-19 (a) TRAVERSE B B' B'' 19.5.77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

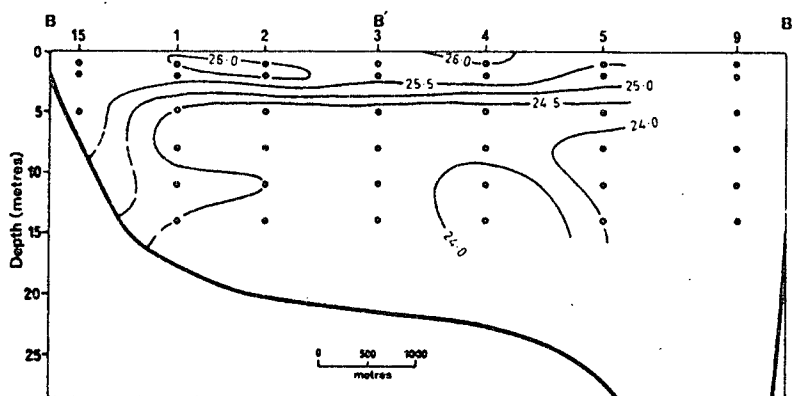


FIGURE 4.19 (b) TRAVERSE B B' B'' 24.5.77

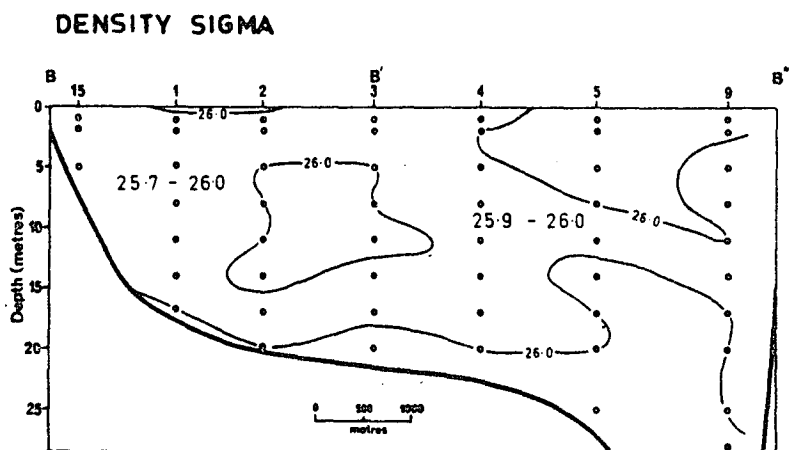
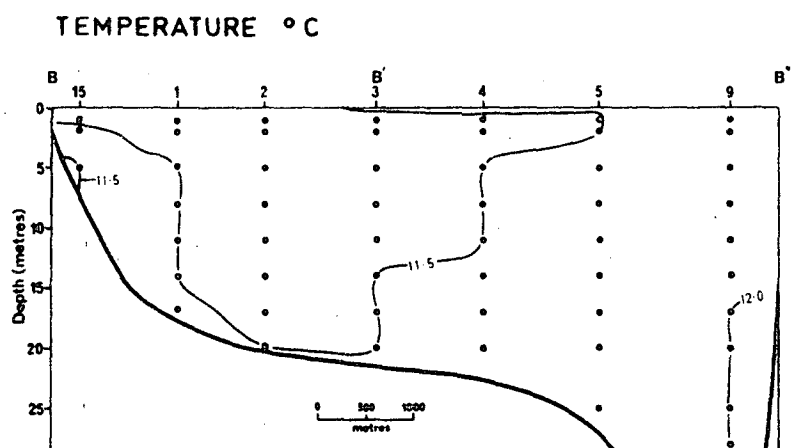
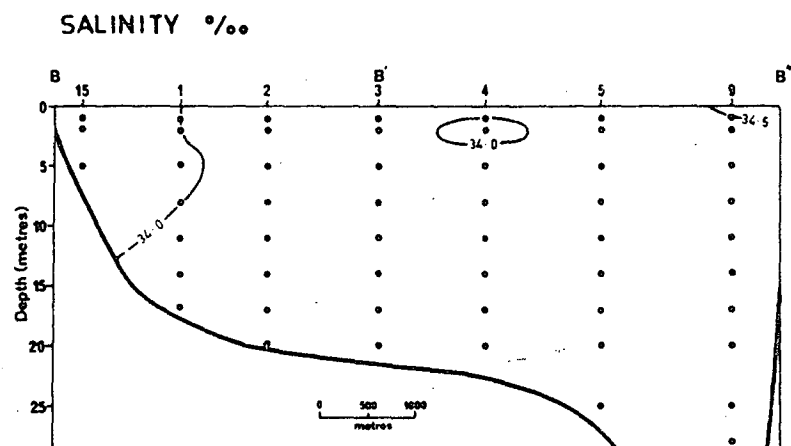
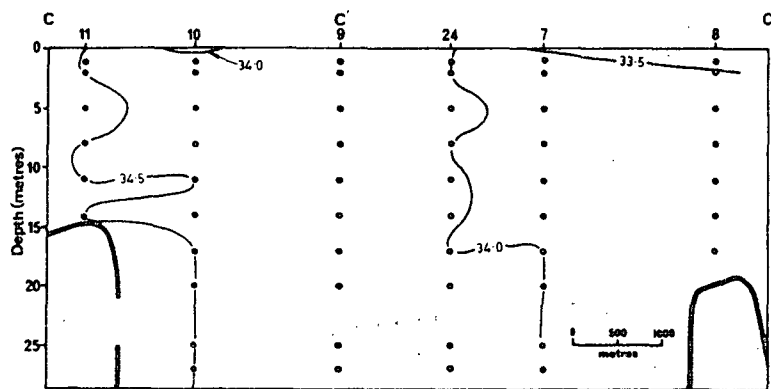
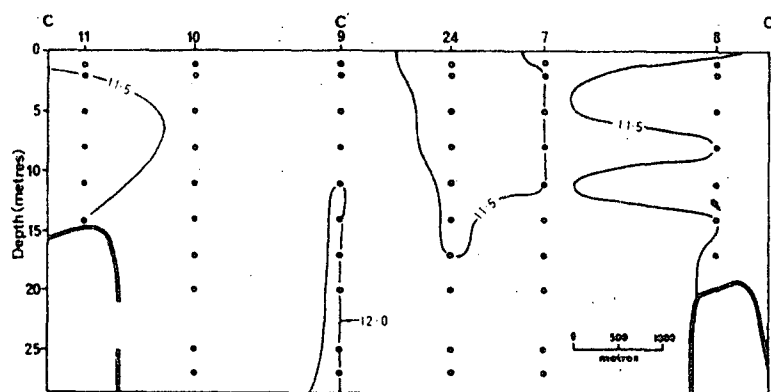


FIGURE 4-19 (c) TRAVERSE B B' B'' 4-6-77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

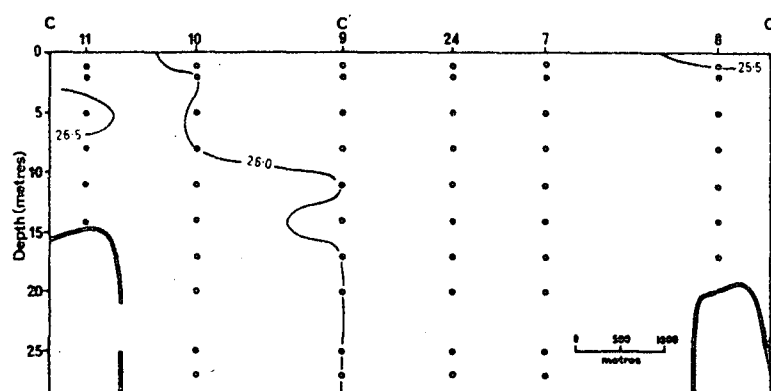
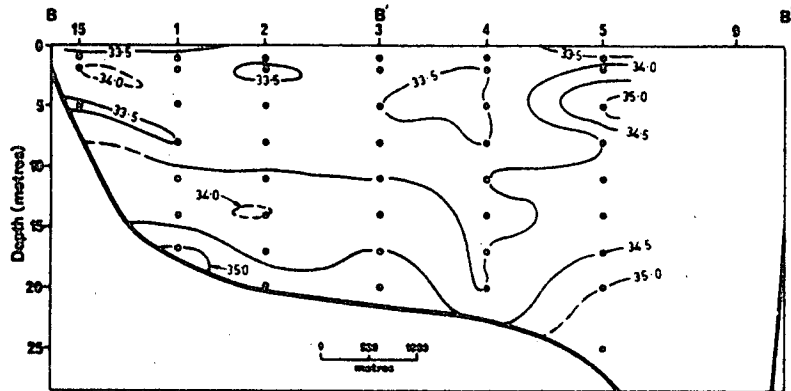
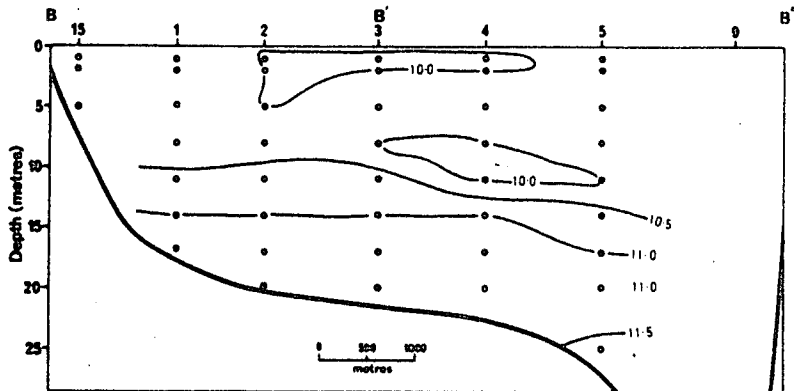


FIGURE 4.19(d) TRAVERSE C C' C'' 4.6.77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

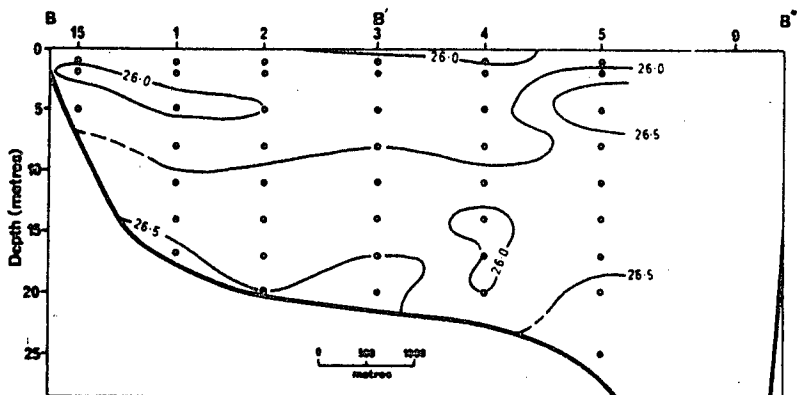


FIGURE 4-19(e) TRAVERSE B B' B'' 11-6-77

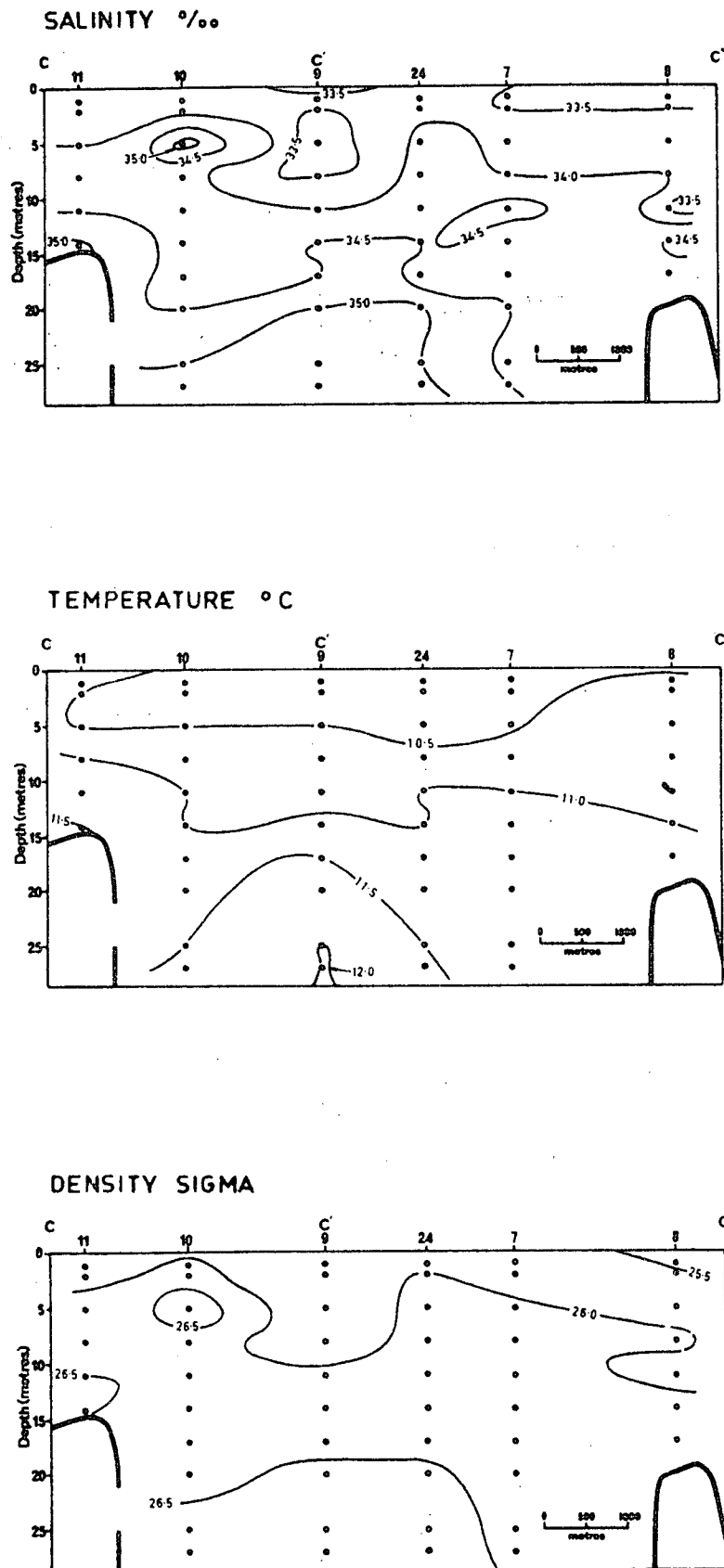


FIGURE 4.19 (f) TRAVERSE C C' C'' 11.6.77

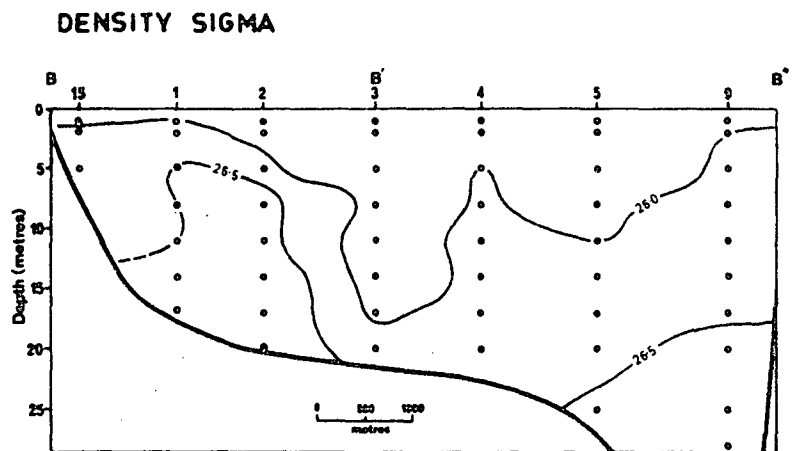
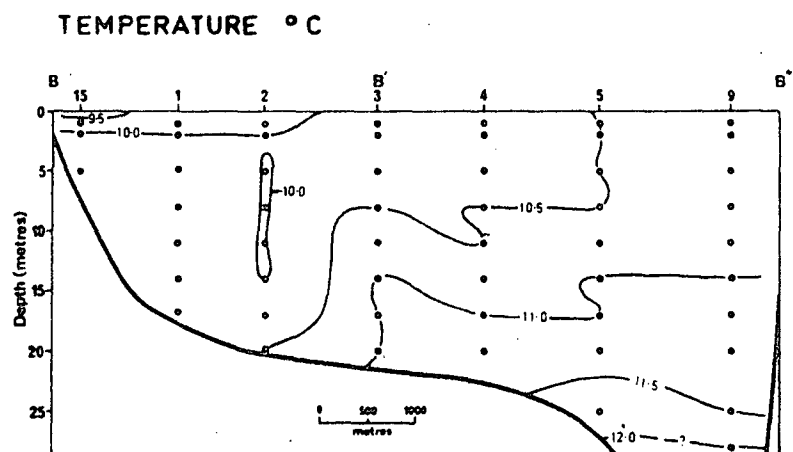
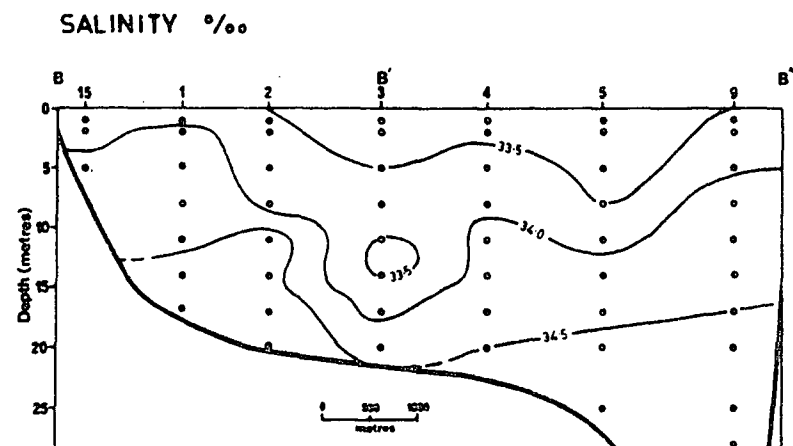
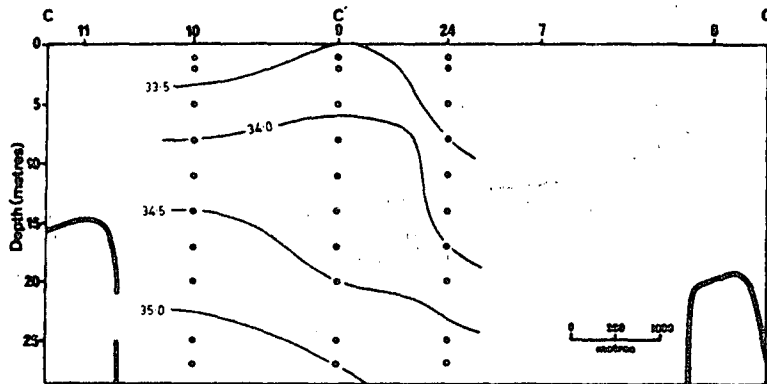
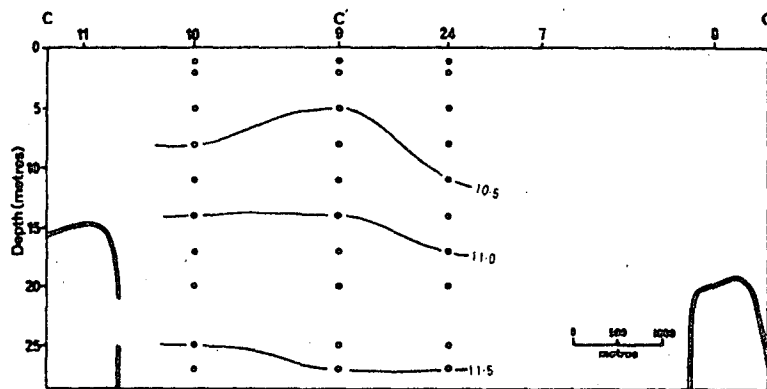


FIGURE 4-19 (g) TRAVERSE B B' B'' 6-7-77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

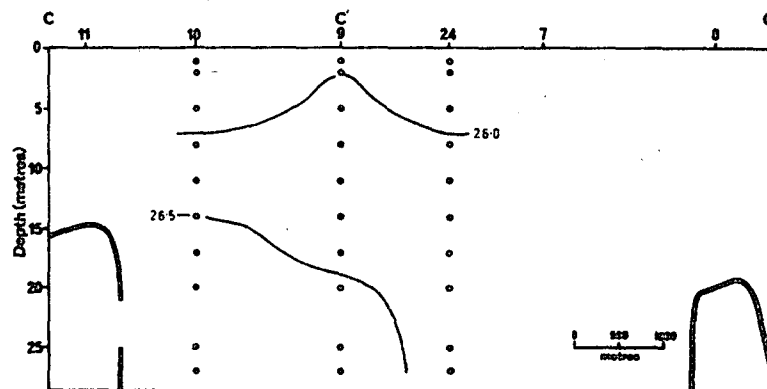
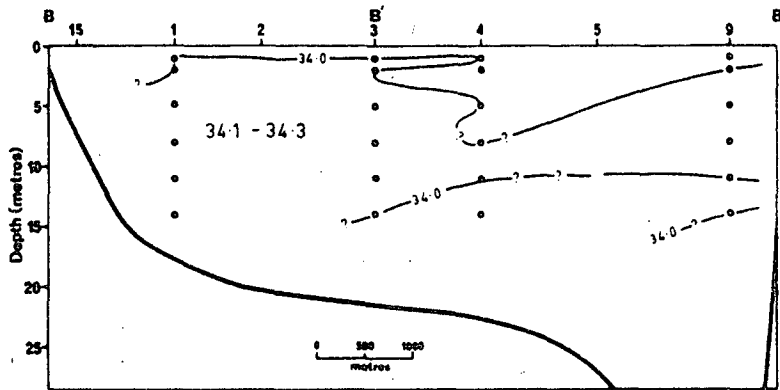
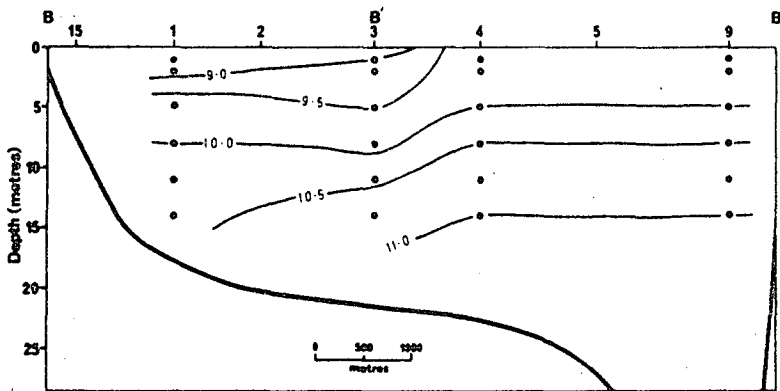


FIGURE 4-19 (h) TRAVERSE C C' C'' 6-7-77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

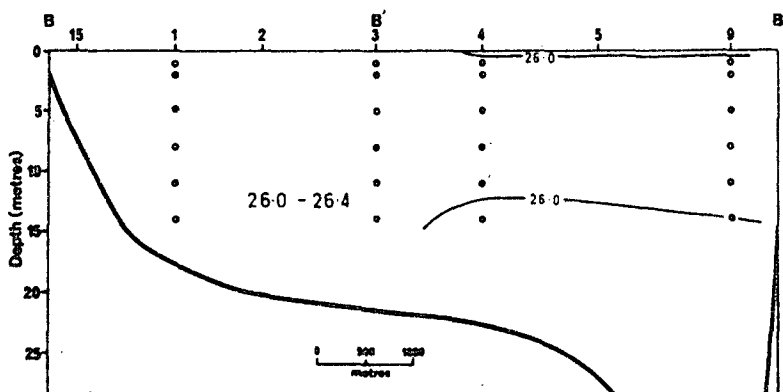
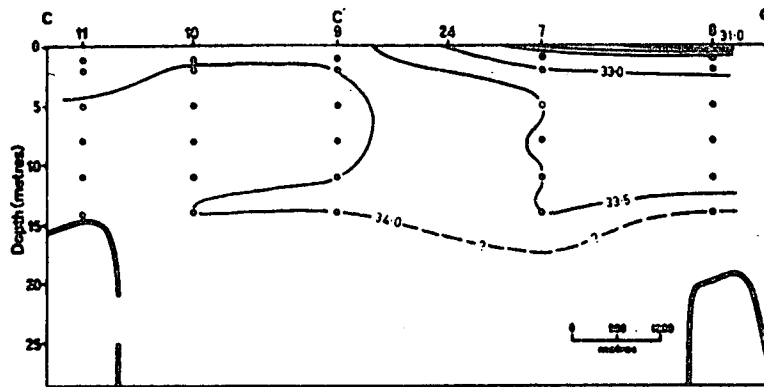
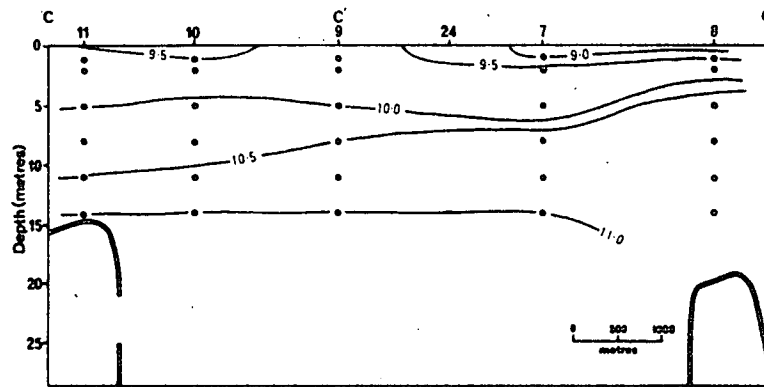


FIGURE 4.19 (i) TRAVERSE B B' B'' 19.7.77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

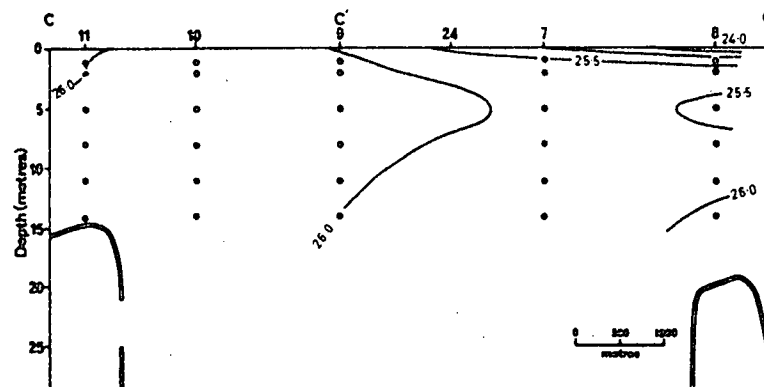


FIGURE 4.19 (j) TRAVERSE C C' C'' 19.7.77

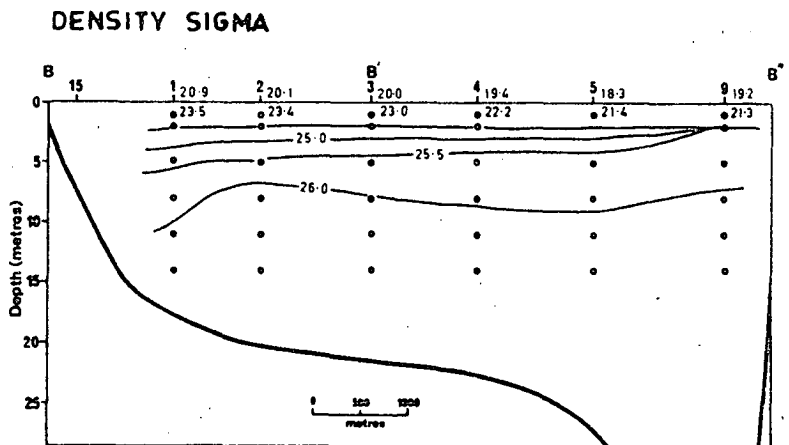
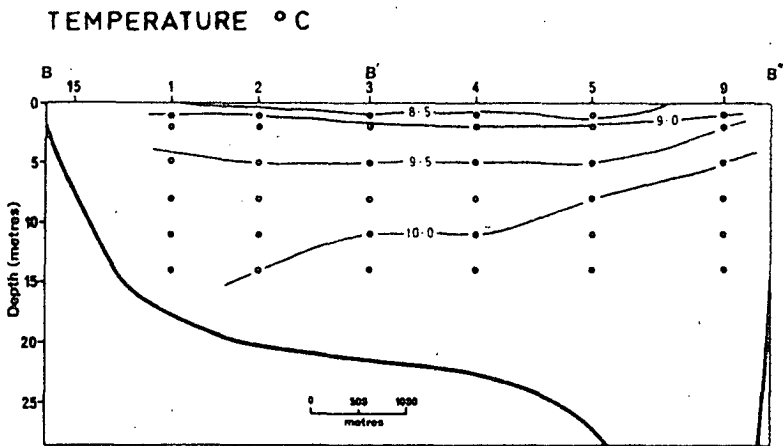
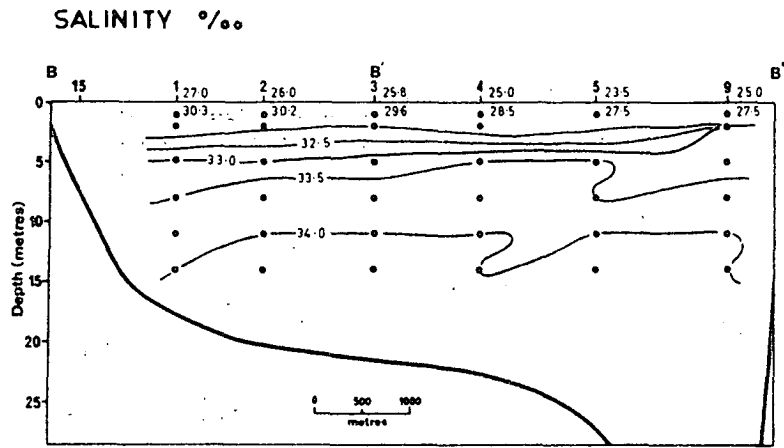


FIGURE 4.19 (k) TRAVERSE B B' B'' 30.7.77

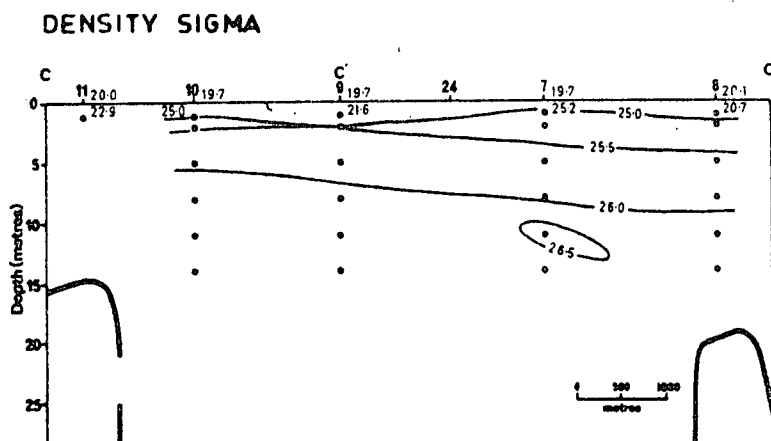
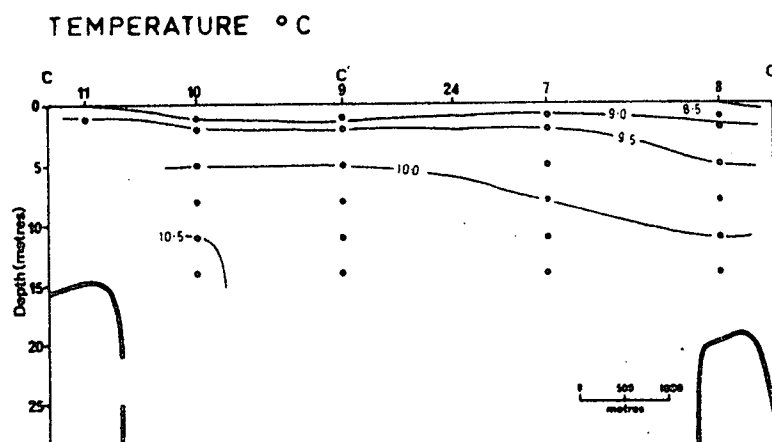
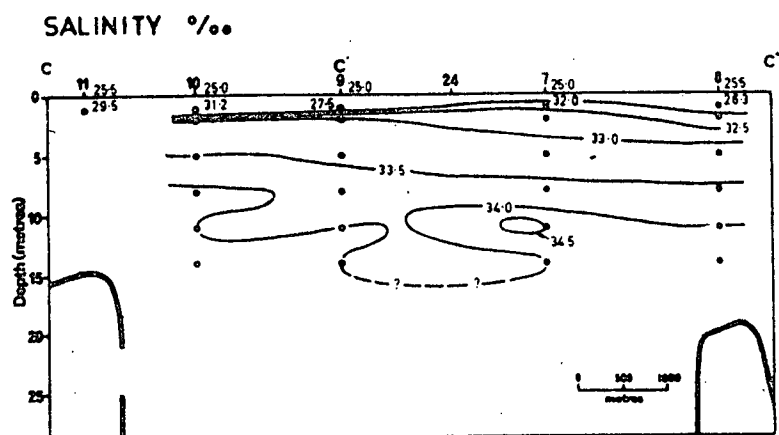


FIGURE 4-19(1) TRAVERSE C C' C'' 30-7-77

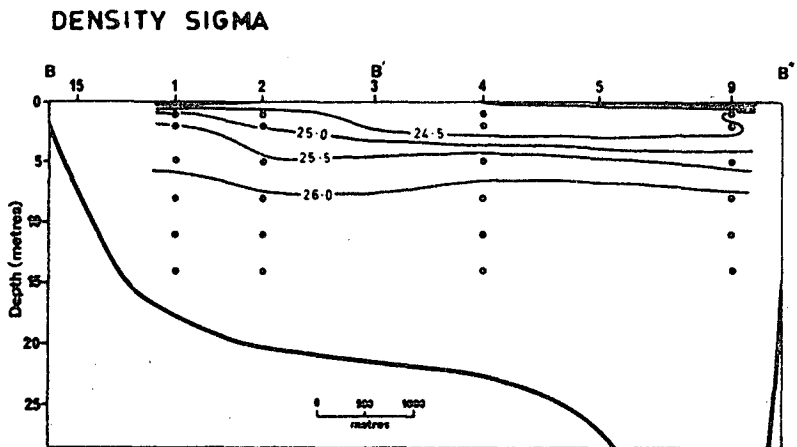
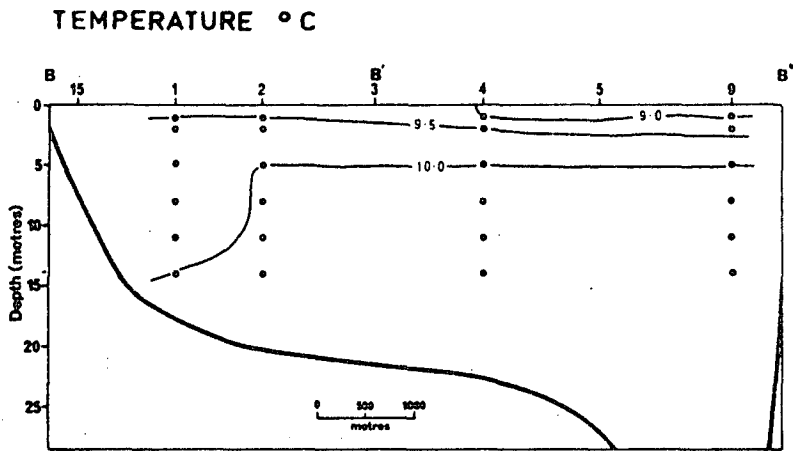
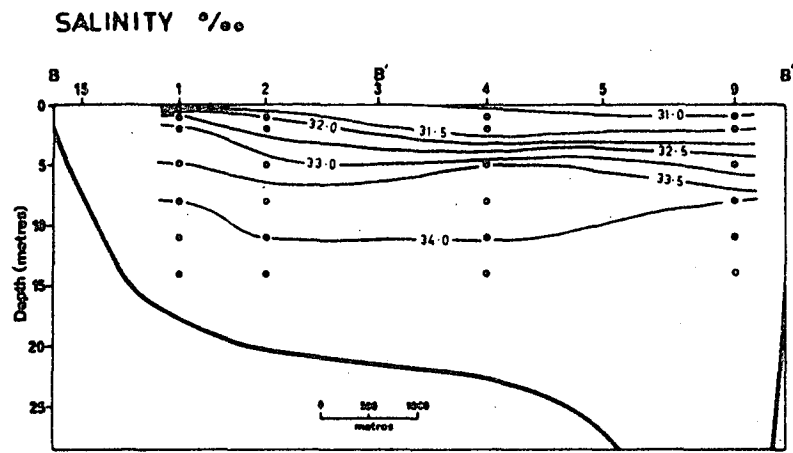


FIGURE 4.19 (m) TRAVERSE B B' B'' 2.8.77

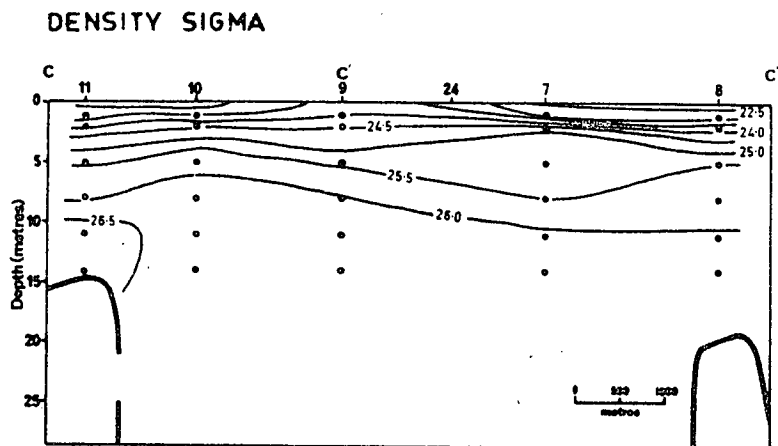
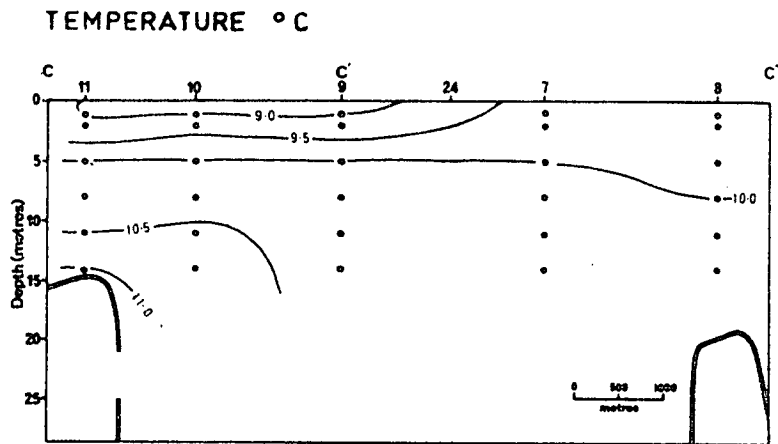
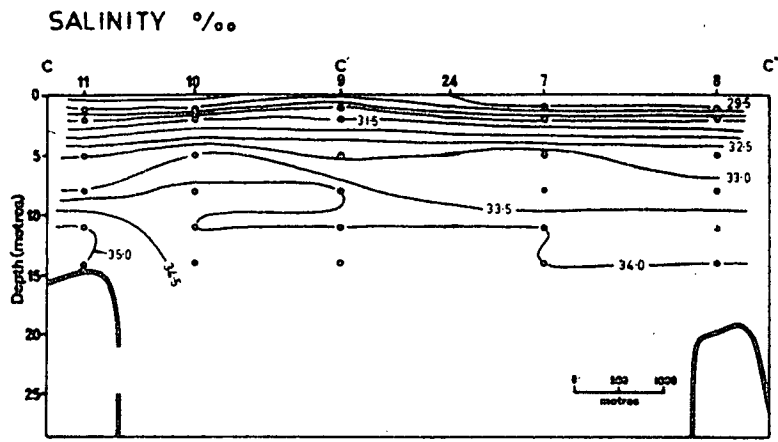


FIGURE 4.19 (n) TRAVERSE C C' C'' 2.8.77

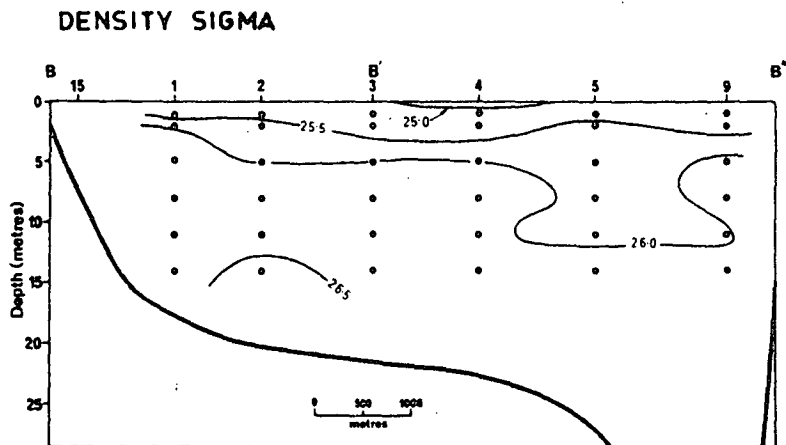
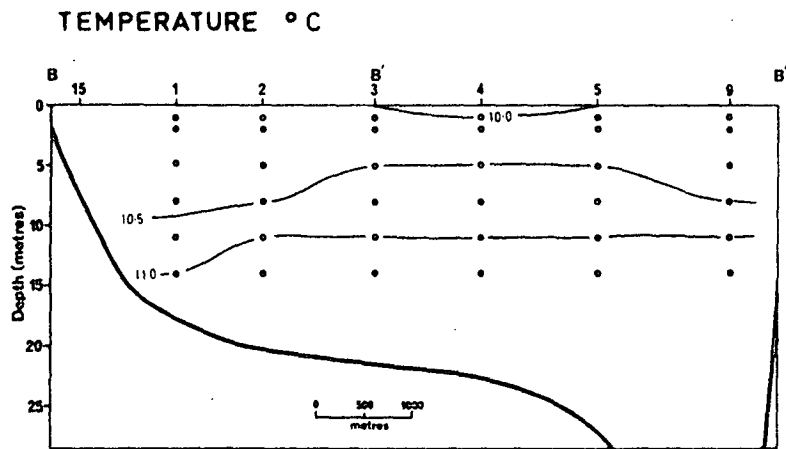
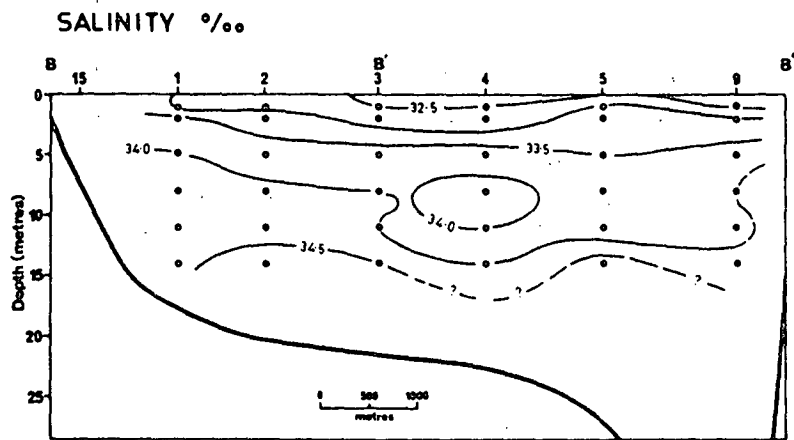
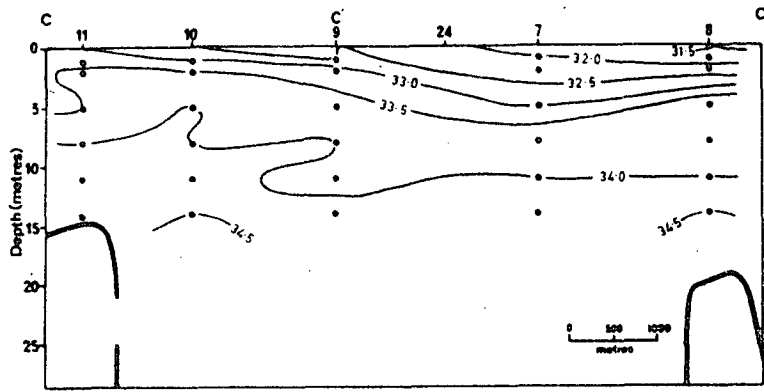
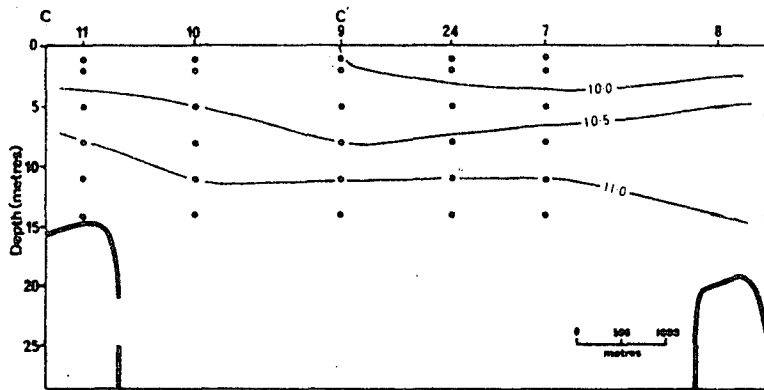


FIGURE 4.19 (o) TRAVERSE B B' B'' 6.8.77.

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

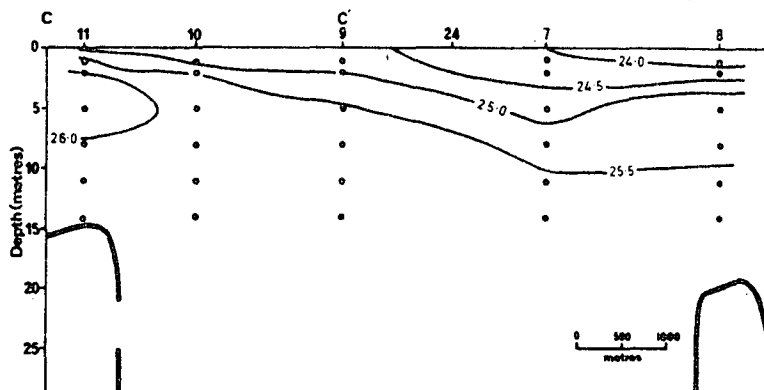


FIGURE 4.19 (p) TRAVERSE C C' C'' 6.8.77

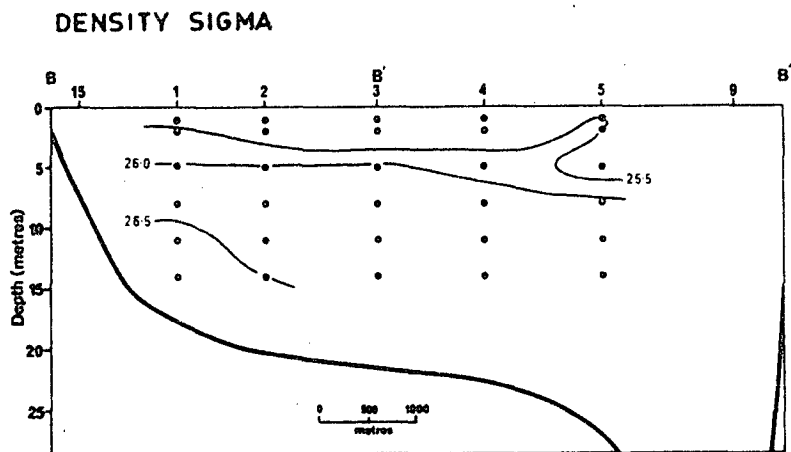
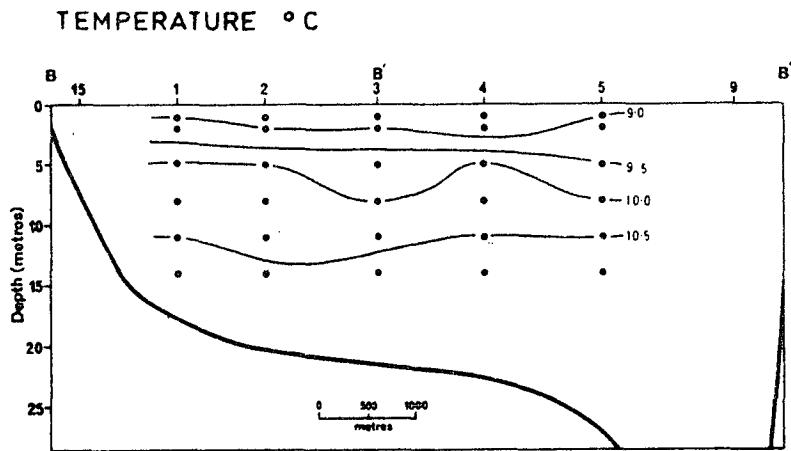
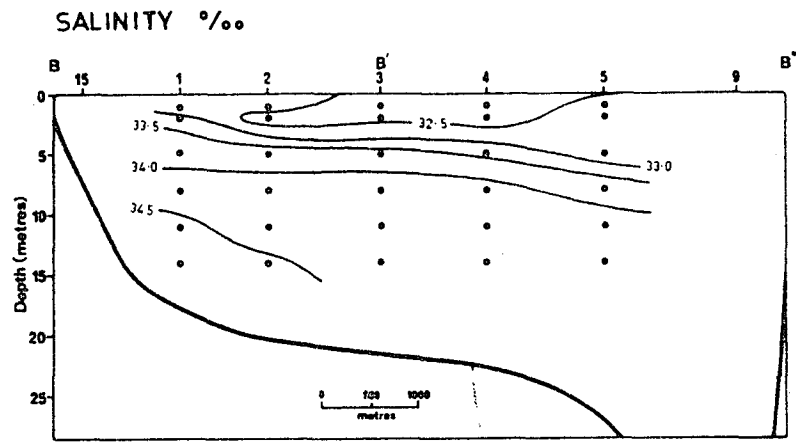
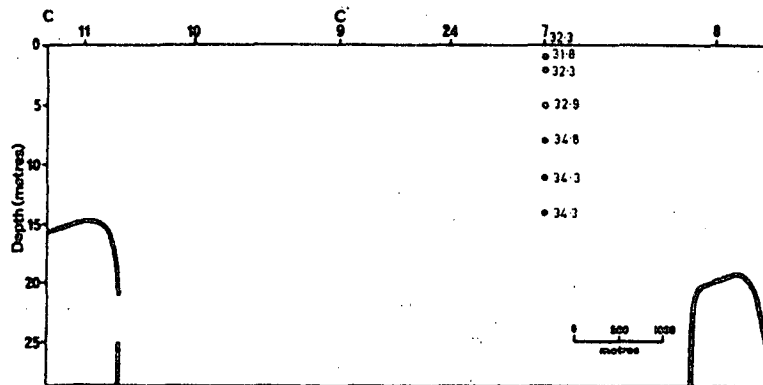
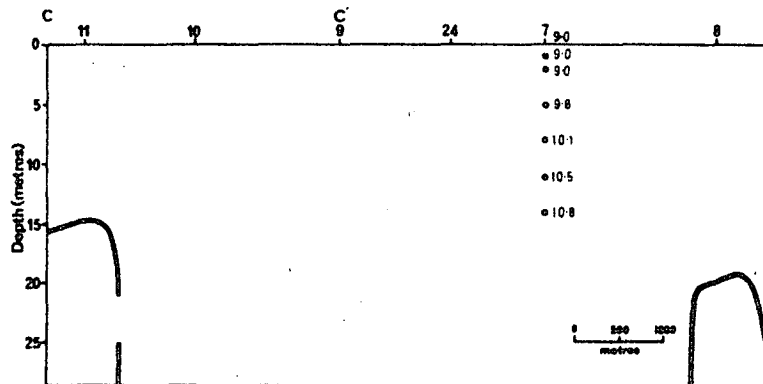


FIGURE 4-19 (q) TRAVERSE B B' B'' 9-8-77

SALINITY ‰



TEMPERATURE °C



DENSITY SIGMA

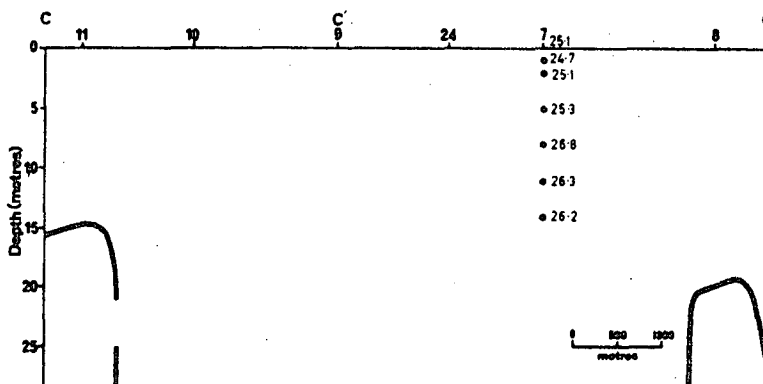


FIGURE 4-19(r) TRAVERSE C C' C'' 9-8-77

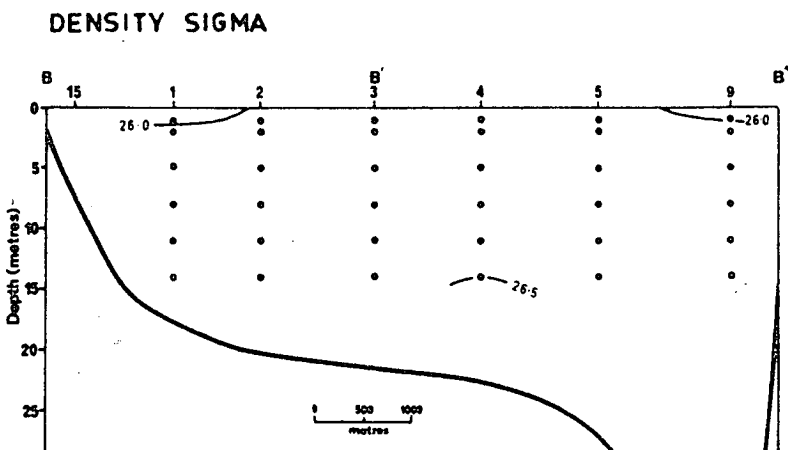
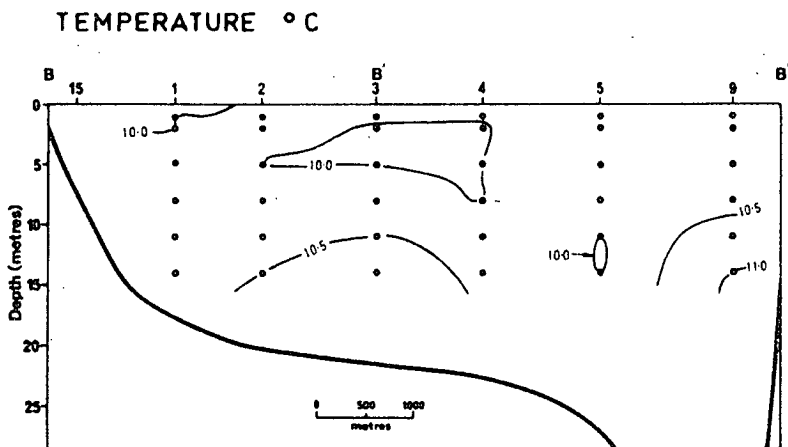
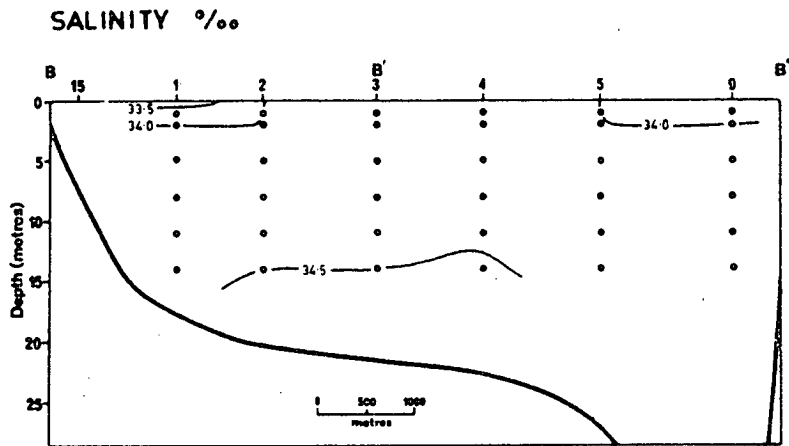


FIGURE 4.19 (s) TRAVERSE B B' B' 22.8.77

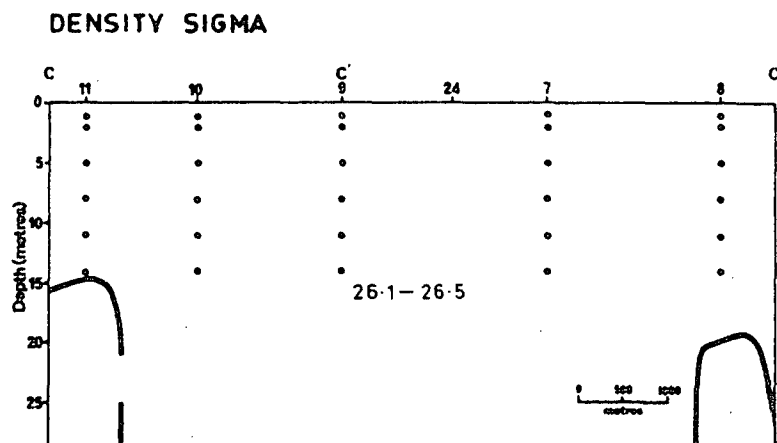
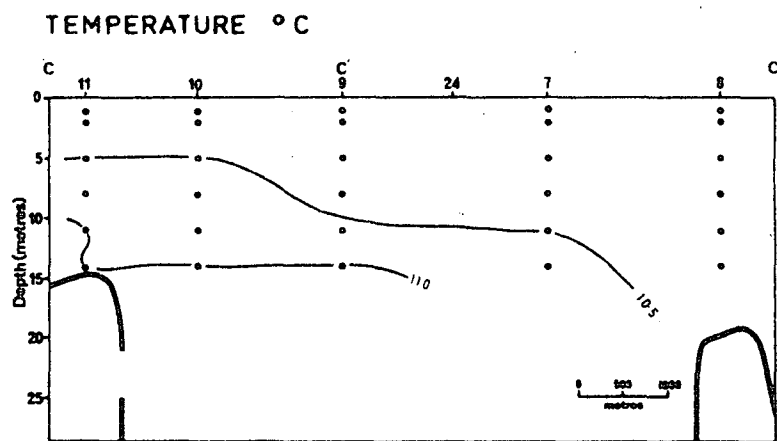
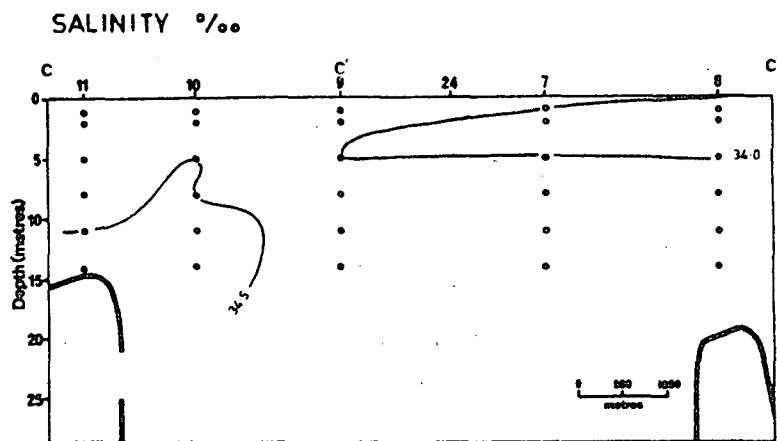


FIGURE 4.19 (t) TRAVERSE C C' C'' 22.8.77

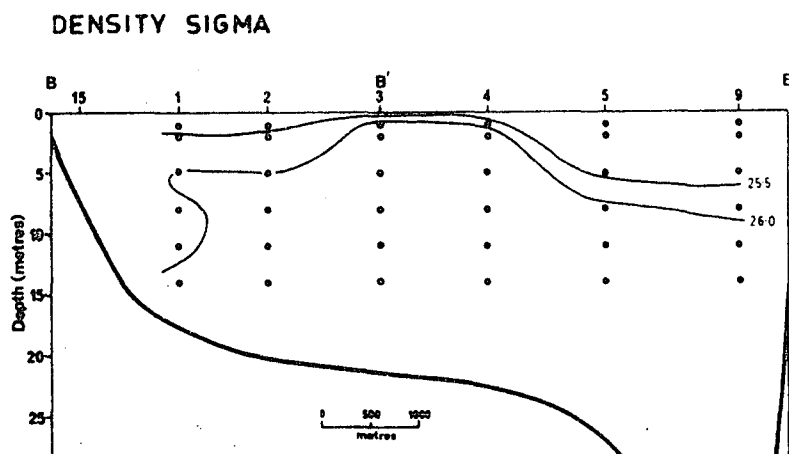
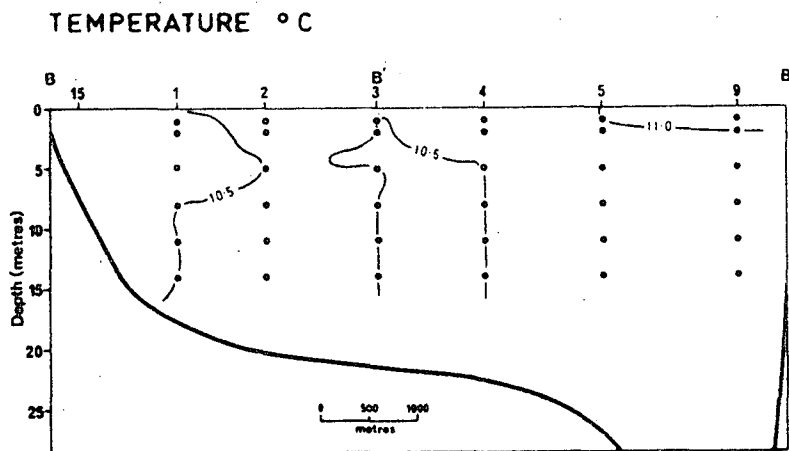
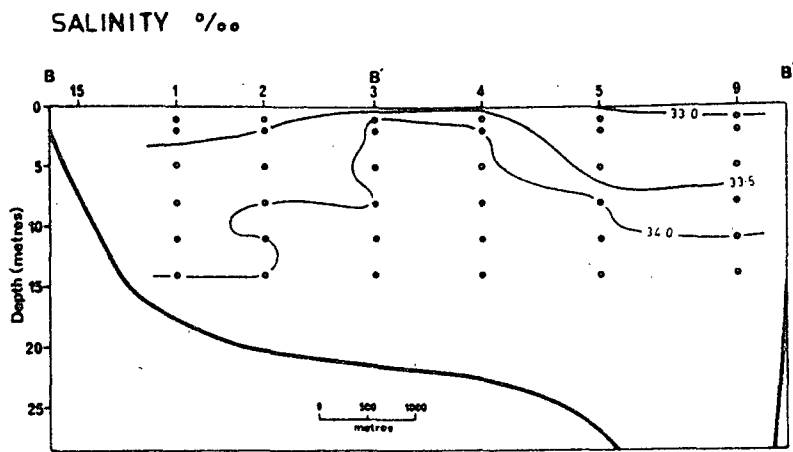


FIGURE 4-19 (u) TRAVERSE B B' B'' 7-9-77

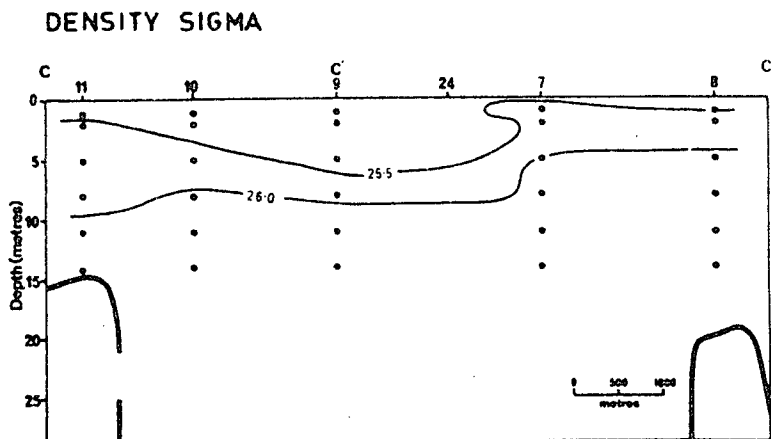
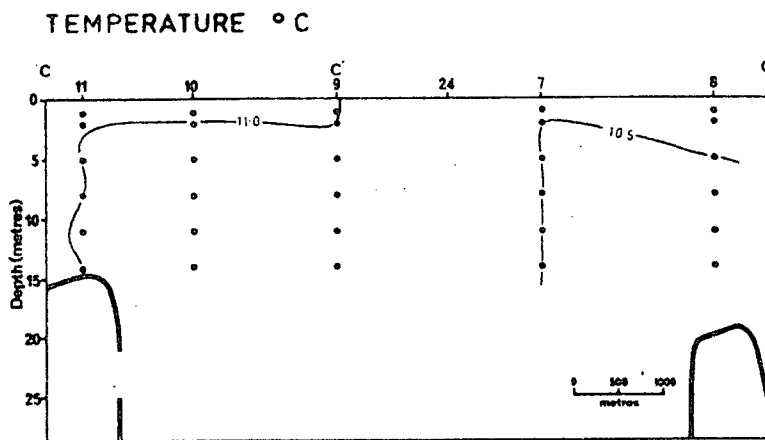
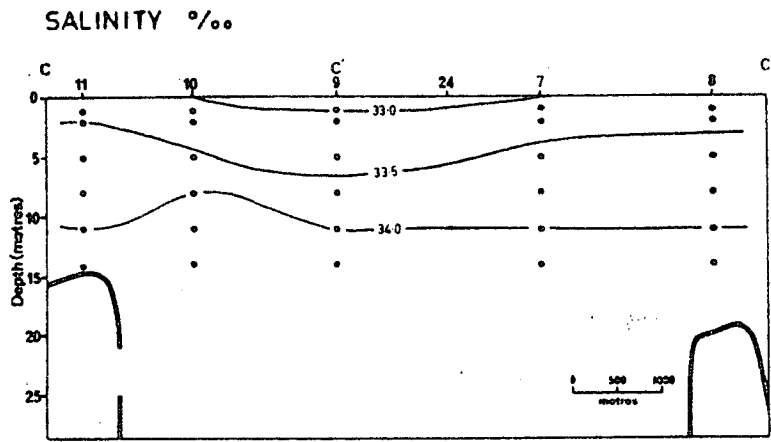


FIGURE 4-19 (v) TRAVERSE C C' C'' 7-9-77

Most of the bay can be expected to be marine throughout the year with salinities generally fluctuating between 32‰ and 35‰. There is generally some slight vertical stratification present, although on odd occasions (see Figure 4.19c and i) the bay can be well mixed. Small but significant changes in the salinity-temperature structure can occur in less than a week (see Figure 4.19a-f).

Following periods of heavy rainfall, such as occurred in late July (see Appendix B), near surface salinities can fall well below 30‰ and more intense vertical stratification develops. Without sustained rainfall such stratification 'decays' fairly rapidly (see Figure 4.19k-t).

A particularly interesting feature that emerges from this data is that there is generally very little longitudinal (seaward) gradation of salinity in the bay; that is, the contours tend to be horizontal. This would indicate that fairly rapid longitudinal (and also lateral) exchange occurs.

The variation in the mean water temperature of North West Bay at three different depths is summarised in Figure 4.20. The temperature changes show a number of distinct features. An anomolous rise occurred between 19 and 24 May corresponding to a total heat gain of 700 kcal per cubic metre. This was followed by a sharp drop between 24 May and 11 June, corresponding to a heat loss of approximately 3500 kcal per cubic metre. After this, with the exception of near surface layers, temperatures generally remained stable fluctuating between 10°C and 11°C.

4.2.2 Freshwater content

The observed fluctuations in salinity can be expressed as a variation in the freshwater content (Q) of the bay, provided some sea water 'reference' can be established. The freshwater content can then be estimated from the relation

$$Q = \frac{S_s - S}{S_s} \cdot V$$

where S_s = salinity of sea water

S = the mean salinity
of the bay

V = total volume of the bay

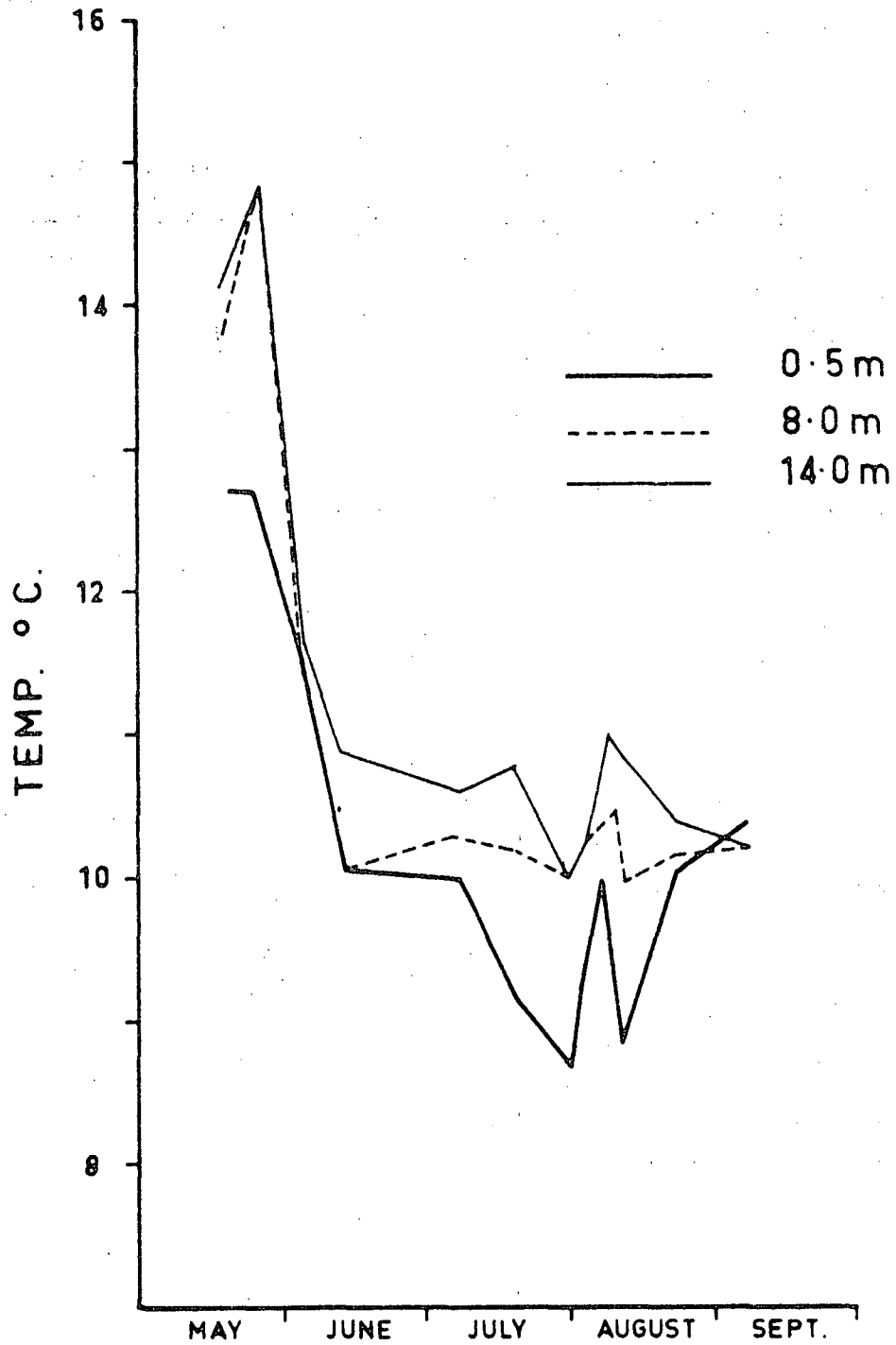


Figure 4.20

Water temperature of North West Bay,
at three depths, during the study
period

On the basis of Taw's¹² observations in Storm Bay, a value of $S_s = 34.6\%$ was taken as the seawater reference. To avoid near-shore effects, the 15 metre contour was chosen as the boundary, for estimation of the freshwater content of the bay. These estimates are presented in Figure 4.21.

Variations in the flow of the Snug and North West Bay Rivers are shown in Figure 4.22 and can be considered to be representative of the changes in freshwater discharge into the bay (see Section 2.3). It can be seen that changes in the freshwater content of the bay do not always correlate with variations in the freshwater discharge. In fact, the highest freshwater content that was observed (24 May) occurred after a long period of very low river flow. This suggests the influence of other estuarine waters on North West Bay.

4.2.3 External influences

While it is obvious that North West Bay is continually under a coastal or oceanic influence, at times there is also evidence for a distinct intrusion of other estuarine waters. This can be inferred from anomalous or distinctive features in the salinity-temperature data.

Between 19 and 24 May there is evidence for an intrusion of a warm (15°C) water mass of low salinity (see Figure 4.19a-b) which on 19 May appears to be intruding at a depth between 4 and 8 metres. The lowest salinity observed for this water mass was 32‰ at station 12 (see Appendix C). This intrusion was associated with the highest temperature and freshwater content recorded in the bay over the study period.

The heat gain (700 kcal/m^3) during this period cannot be attributed to solar radiation or atmospheric pressure exchange since :

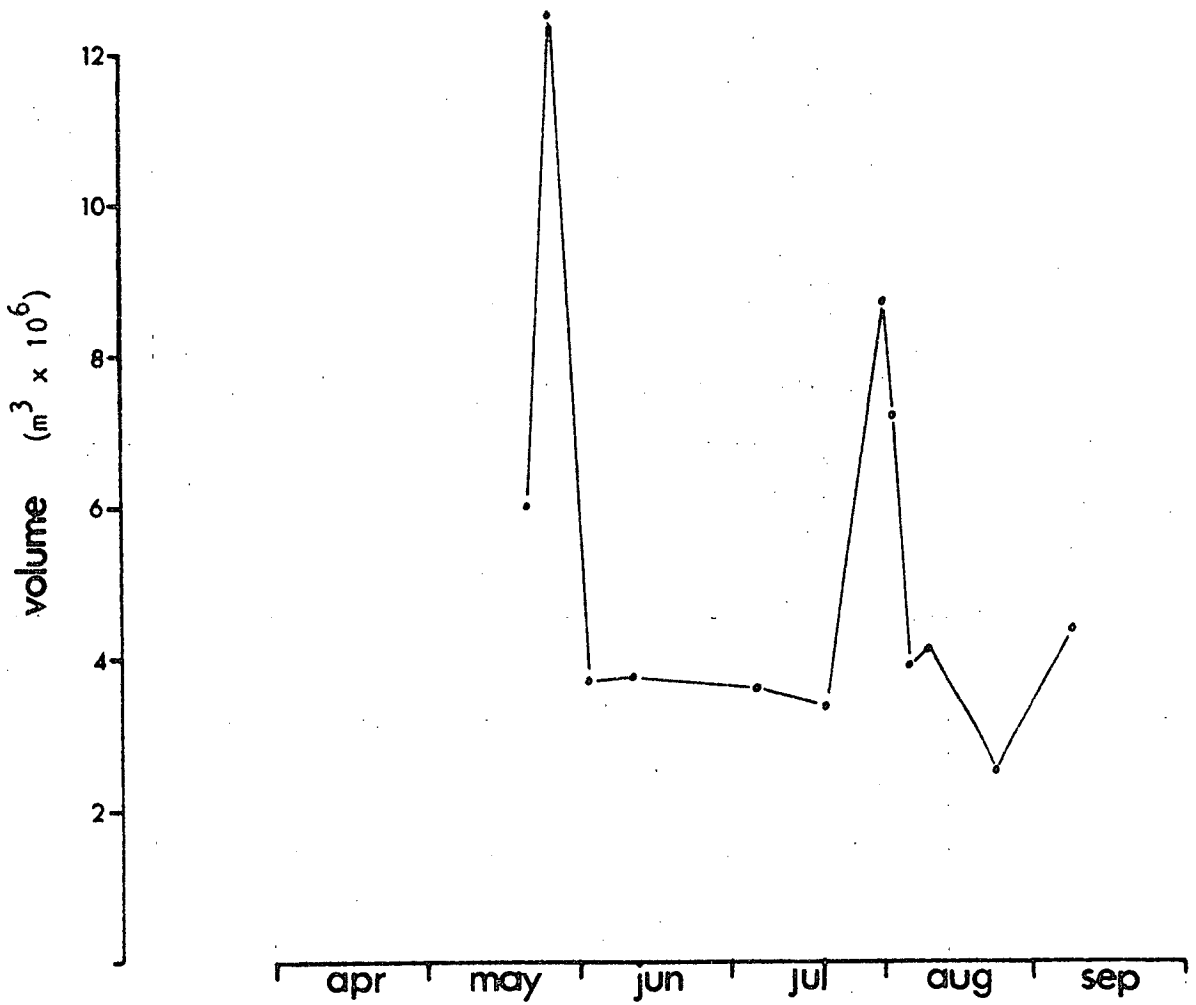


Figure 4.21 Freshwater content of North West Bay

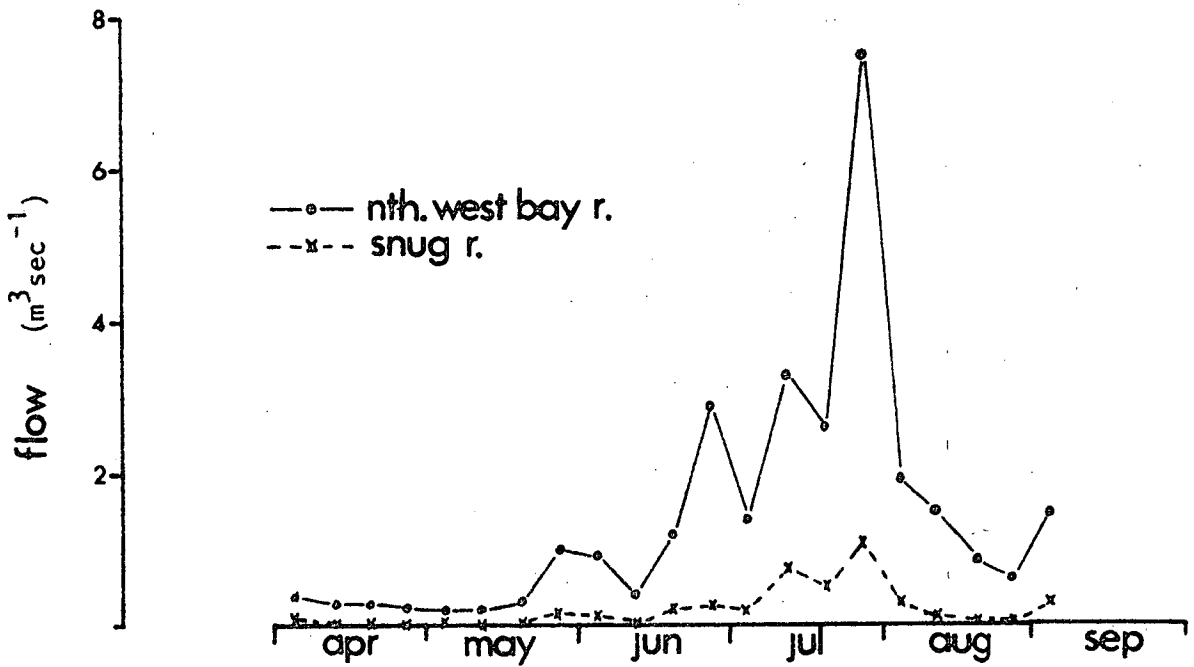


Figure 4.22 Freshwater flow from the Snug and Northwest Bay rivers

- . the heat flux of $320 \text{ cal cm}^{-2} \text{ day}^{-1}$ required across the surface of the bay would be about eight times that expected at equatorial latitudes¹⁴.
- . A negative heat flux could in fact be expected since, apart from the near surface layers, the daily maximum atmospheric temperature (see Appendix B) was generally lower than the temperature of the bay.
- . The low temperature of the surface layers suggests that a radiant or convective heat loss to the atmosphere is in fact occurring.

Although the origin of this water mass is difficult to define, its salinity indicates that it must be estuarine, and the salinity and temperature gradients across the mouth of the bay suggest that it originates from the Derwent estuary.

Similarly the sharp drop in temperature between 24 May and 11 June, if attributed to atmospheric exchange, would require a heat loss with a flux five times that expected at polar latitudes¹⁴. It can be seen by referring to Figure 19c-f that this change is best attributed to the influence of two distinct masses of cold water, one of higher salinity ($> 34.5\%$) from Storm Bay, and the other of lower salinity ($< 33.5\%$) from the D'Entrecasteaux Channel.

It was indicated in Section 2.5 that Taw's¹² data suggested a gradient of decreasing salinity down the D'Entrecasteaux Channel. This tends to be a consistent feature observed in this study (see Figures 4.19d,f,h,j,p), with the gradients being more pronounced in the near surface layers. These gradients suggest an estuarine influence from the lower part of the channel which could only emanate from the Huon River. However, this cannot be demonstrated conclusively from the present data.

4.2.4 Rates of exchange

Since the direct freshwater influx into the bay is small, changes in the freshwater content of the bay are often dependent on the influence of adjacent waters. This presents a problem in determining the rate at which the bay water is exchanged. However, observations suggest that water exchanges may occur fairly rapidly.

Sharp changes in the freshwater content of the bay can occur in less than a week (see Figure 4.21) and the lack of longitudinal salinity gradients indicates that these changes are transmitted throughout the bay fairly rapidly. The rate at which these changes occur is well illustrated by the observation between 19 May and 11 June (see Figure 4.19a-f). Hence it would appear that a significant proportion of the bay water must be exchanged over a period of about one week.

If some assumptions are made, two different approaches can be used to obtain a rough estimate of the exchange rate.

Assume that the freshwater accumulation (Q) within the bay attains a steady state with the average river influx (R). Then if r is the proportion of the bay water removed daily, that is, the exchange ratio, then it follows that

$$r = \frac{R}{Q}$$

provided that complete mixing is assumed.

Now Q can be estimated from the average freshwater content of the bay, ignoring the 'spikes' for 24 May and 30 July which are thought to represent transient influences (see Figure 4.21). If R is taken on Badcock's¹⁵ estimate of the annual freshwater influx ($117.8 \times 10^6 \text{ m}^3 \text{ a}^{-1}$) then an exchange ratio of 1:11 is obtained. However, Badcock's¹⁵ estimates are based on an average annual flow of $2.95 \text{ m}^3 \text{ sec}^{-1}$ for the North West Bay River, while the average flow over the period covered by the salinity-temperature observations

was only $1.78 \text{ m}^3 \text{ sec}^{-1}$. Thus if the freshwater discharge can be extrapolated on the basis of this lower river flow, the estimated exchange ratio is then 1:6.6.

Alternatively, an estimate of the exchange ratio can be made from the change in the freshwater content between 19 and 24 May. If S_i is the salinity of the intruding water mass, then the proportion (p_i) of the bay water that has been removed is given by

$$p_i = \frac{S_2 - S_1}{S_i - S_1}$$

where S_2 = final salinity of the bay

S_1 = initial salinity of the bay

Let r be the proportion of the total volume of the bay that is exchanged daily (that is, the exchange ratio). Then provided complete mixing can be assumed, and r remains constant, it follows that

$$(I - p_i) = (I - r)^n$$

where n = number of days over which the exchange occurred

If we ignore the near surface layers (the high surface salinities on 24 May are thought to represent a wind effect), and assume a value $S_i = 32\%$ for the salinity of the intruding water mass, the estimated exchange ratio is 1:6.2. This calculation can be repeated for the salinity changes that occurred between 24 May and 4 June. If a value $S_s = 34.5\%$ is assumed (the salinity at the mouth of the Channel on 4 June) then an exchange ratio of 1:7.7 is obtained. Since there is evidence on 4 June (see Figure 4.19d) that higher salinity ($> 34.5\%$) water from Storm Bay is mixing with lower salinity ($< 33.5\%$) water in the Channel, this value $S_s = 34.5\%$ can be reasonably assumed to be an upper limit.

While these estimates are rough, they indicate that the exchanges between the bay and its adjacent waters are much greater than would be expected from the tidal prism calculation, probably by a factor of more than two.

4.2.6 Other Phenomena

The role of some other phenomena in the exchange and mixing processes can be inferred from the salinity and temperature data, although not conclusively.

While wind undoubtedly acts as a transient mixing process, at times it may also contribute to water exchanges. The high surface salinities, observed on 24 May, are difficult to explain as other than an influx from Storm Bay under the influence of winds. Downwelling on the western shore adds credibility to this hypothesis (see Figure 4.19b).

At times current profiles may not be uniform with depth. Thus, for example, on 19 May there is evidence that lower salinity water is intruding at a depth between four and eight metres (see Figure 4.19a).

Such intrusions may be spasmodic with a cellular circulation developing during quiet phases (see Figure 4.19a) as a process for absorbing energy. Such cells might only form, in preference to eddies, under the influence of gravitational convection.

4.2.7 Summary

The most important conclusions that can be drawn from the salinity and temperature data are

- . Small but significant changes in the salinity-temperature structure can occur in periods of less than a week.
- . The lack of longitudinal (and lateral) salinity gradients show that these changes tend to be rapidly transmitted throughout the bay.
- . At times other estuarine waters influence the freshwater content of the bay.
- . Exchanges between the bay and adjacent water are greater than would be expected from the tidal prism and the (daily) exchange ratio may be in the order of 1:7. (Note that the inverse of this ratio is often referred to as the flushing time).

4.3 Circulation

The nature of the driving mechanisms (see Section 4.)) indicates that the circulation patterns in the study area will be complex. The strong meteorological influence indicates that flows will not be predictable simply on the basis of tidal periods. Information gathered in this study is not comprehensive enough to determine the detailed circulation structure and therefore the purpose of this section is to discuss unique circulation features and to construct hypotheses for future investigation. This is done by inferring gross circulation patterns from the current meter data, salinity data and some available usual observations. Other features of the circulation within the study area are then presented in the final part of this section.

4.3.1 Gross Circulation

Current meter and simultaneous tide data are the most comprehensive data available from which circulation hypotheses can be constructed.

The times of high and low tide and the levels as predicted by tide tables are compared with those recorded at Hobart and North West Bay, and shown in Table 4.2. Tide data for North West Bay, where available, is similar to both the predicted and recorded tide for Hobart. Averaged current meter records obtained simultaneously across the boundary of North West Bay (positions 1 and 2, see Figure 3.3) are shown in Figures 4.10, 4.11 and 4.12. Velocities recorded by these meters reached a maximum of 30 cm/s, with consistent, sustained flows in excess of 10 cm/s occurring for periods longer than 12 hours. The records also show little correlation with the semi-diurnal period or magnitude. The directional nature of these records is given by the direction frequencies shown in Table 4.3. The record for Meter No. 1 is distinctly bimodal having peaks at 120° and 335° . Meter No. 2 has a less well defined bimodal character with peaks in the ranges $15-105^{\circ}$ and $270-350^{\circ}$.

Table 4.3
CURRENT METER DIRECTION FREQUENCIES

DIRECTION	FREQUENCY		
	Meter No.1	Meter No.2	Meter No.3
5	7	28	3
10	36	34	13
15	11	24	3
20	6	36	3
25	6	33	2
30	13	39	3
35	7	31	1
40	13	33	1
45	9	27	1
50	9	43	1
55	7	34	1
60	8	34	2
65	10	37	3
70	18	35	1
75	15	43	2
80	20	36	1
85	19	35	1
90	33	43	0
95	17	46	1
100	54	27	5
105	35	34	2
110	90	27	6
115	72	22	3
120	92	20	4
125	80	7	5
130	73	9	6
135	56	10	2
140	32	5	3
145	42	6	6
150	52	7	5
155	31	3	5
160	29	3	6
165	27	6	5
170	27	7	3
175	14	1	9
180	18	4	4
185	7	3	1
190	19	8	3
195	6	4	4
200	10	5	7
205	10	2	18
210	6	4	6
215	2	2	13
220	4	4	15
225	7	3	18
230	5	5	25
235	3	12	27
240	3	12	29
245	5	8	23
250	4	8	29
255	6	16	25
260	5	11	45
265	3	17	45
270	5	28	44
275	4	16	72
280	5	41	61
285	11	39	46
290	18	26	48
295	13	25	32
300	28	30	30
305	19	23	33
310	20	30	27
315	24	21	23
320	26	22	28
325	41	19	20
330	67	38	24
335	58	25	16
340	64	32	24
345	42	32	26
350	34	37	11
355	20	36	11
360	44	41	12

These records show the influence of a high energy flow pattern within the D'Entrecasteaux Channel and distinctly opposed flows directed in and out of North West Bay.

Initial tidal prism calculations (see Section 2.4), based on predicted tide levels, indicate that average tidal velocities in North West Bay would be less than 2 cm/s. The currents recorded across the entrance boundary are at least one order of magnitude greater than this, yet the tide levels recorded in the bay are consistent with those predicted. The discrepancy between the tidal prism calculation and the observed current meter velocities has some implications for the circulation pattern if the mass balance within the bay is to be maintained. Two possible flow patterns which satisfy these requirements could be:

- . opposing flows at differing depths
- . opposing lateral flows.

As the current meters were placed at mid depth, the first hypothesis could not be tested. However there is good evidence for the existence of the second flow pattern. This is shown by the distinct and consistent opposing flow pattern of Meters No. 1 and 2 (see Figures 4.10, 4.11 and 4.12).

Further information on the gross circulation patterns in this area is provided by Meter No. 3. This meter operated for approximately two weeks in the inner section of the bay (see Figure 3.3). Unfortunately simultaneous measurements at the entrance of the bay were not obtained. If one assumes that the flow regime at the bay entrance, as shown by Meter Nos. 1 and 2, also existed during the measurement period of Meter No. 3, then a more complete hypothesis can be constructed.

The record of Meter No. 3 displays less than half the energy that was obtained from the meters at the entrance to the bay. Its direction frequency indicates a peak at 275° with a significant range of variation from 220° - 350° (see Table 4.3). Velocities recorded by this meter are lower than

those recorded at the entrance of the bay, with 63% of the values being below 5 cm/s and few above 10 cm/s.

By consideration of all current meter records, it is possible to hypothesise a high energy 'driving' regime at the entrance to North West Bay which is an extension of the flow conditions in the D'Entrecasteaux Channel. Within North West Bay proper a lower energy 'coupled regime', with complex flows, may exist. The nature of the boundary between these two regimes can be expected to vary depending upon the relative state of the driving mechanisms of the area. A sketch of this gross circulation pattern is shown in Figure 4.23.

Visual observations obtained during the study period tend to reinforce the character of this circulation pattern. These include:

- . the occasional large drag placed on the salinity meter probe at the mouth of the D'Entrecasteaux Channel as mentioned in Section 3.2.3.
- . a well defined 'rip' line, suggesting a turbulent interface, which extended from the mouth of the D'Entrecasteaux Channel to North West Bay. This 'rip' line was observed on three occasions (11 June, 16 July, 30 July) and is shown in Figures 4.24 and 4.25.
- . the observation of a discoloured freshwater flow from the North West Bay River during a period of high rainfall (29 mm) from 28-29 July. This tracer flowed as a narrow stream down the eastern shore with a pronounced bulge toward the mouth of the bay (see Figures 4.24 and 4.26). It is thought that this bulge may reflect the boundary between the two regimes.

The stream followed by the discoloured freshwater tracer is also mirrored in the salinity observations between 30 July and 9 August. During this period near surface salinities are

consistently lower along the eastern shore of the bay (see Appendix C, stations 12 and 13), and the 'freshwater' bulge can be seen in the near surface salinities between stations 4 and 5 (see Figure 4.19k,m,o,q). The cellular structure observed on 19 May (see Figure 4.19a) might add evidence for the existence of a boundary near the mouth of North West Bay.

4.3.2 Other phenomena

An interesting feature of the tide record during the period 27 July - 2 August was the occurrence of apparent large changes in water level within periods of less than five minutes. During this period, these occurred consistently at times of low tide. This is illustrated in two sections of the tide record shown in Figure 4.27. Two possible explanations for this phenomenon are:

- . water level changes due to resonance (seiches) within North West Bay.
- . internal waves exerting short period pressure fields on the tide gauge transducer without any actual water level change.

If these changes were due to seiches they would represent water level changes of up to 0.3 metres for periods of less than five minutes. Also one might expect seiches to occur at other times, but this phenomenon was not observed on the later part of the record from 2 August - 21 September. Salinity data available for this period (see Figure 4.19k-n) indicates that strong stratification existed in the surface layers of the bay. This tends to reinforce the case for internal waves¹⁶ which may be generated at low tide by the turbulent driving regime at the entrance to North West Bay.

Further evidence for internal waves is provided by photographs taken on 31 July (see Figure 4.28) which show closely grouped transverse slicks in the D'Entrecasteaux Channel.

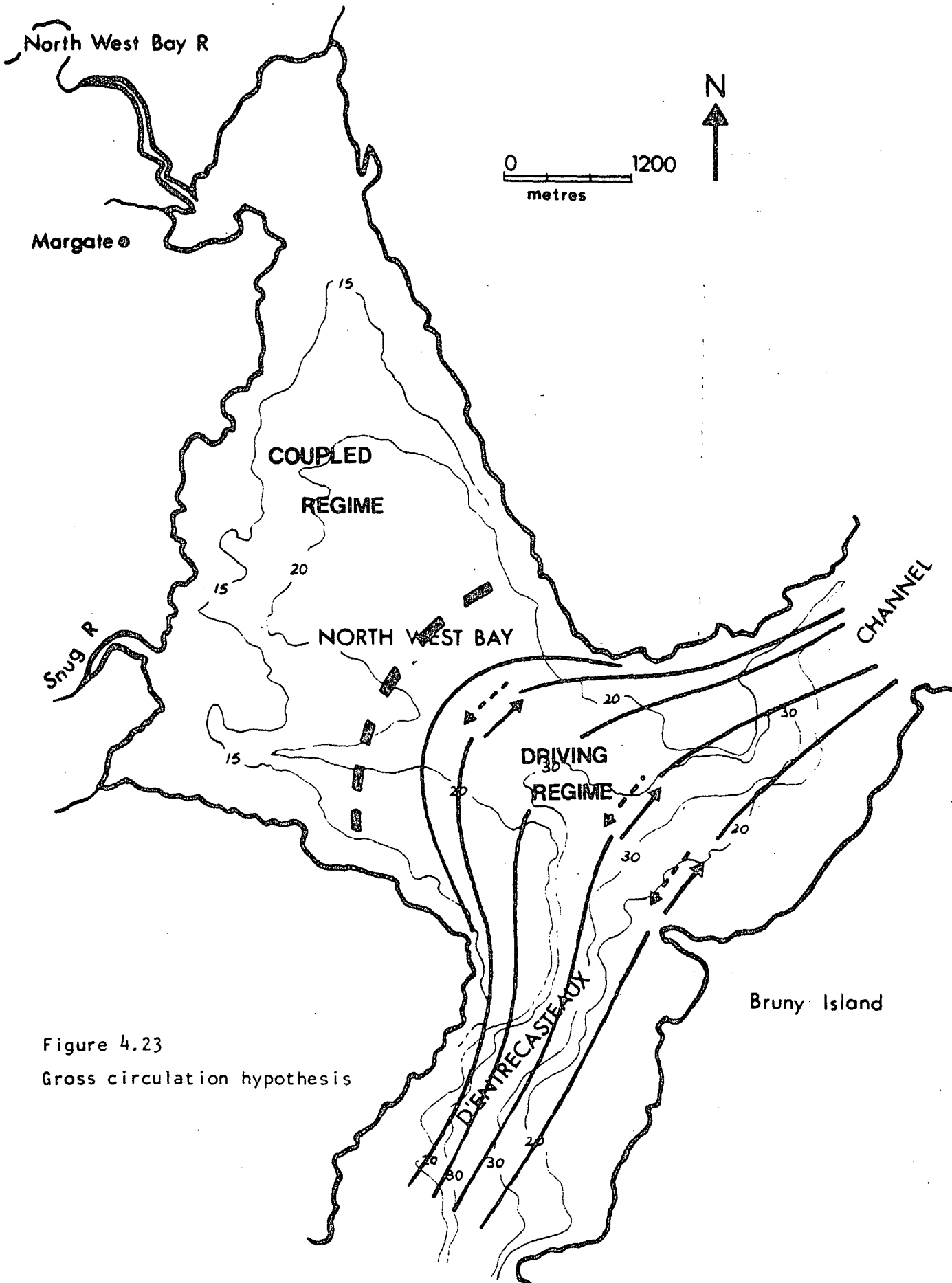


Figure 4.23
Gross circulation hypothesis

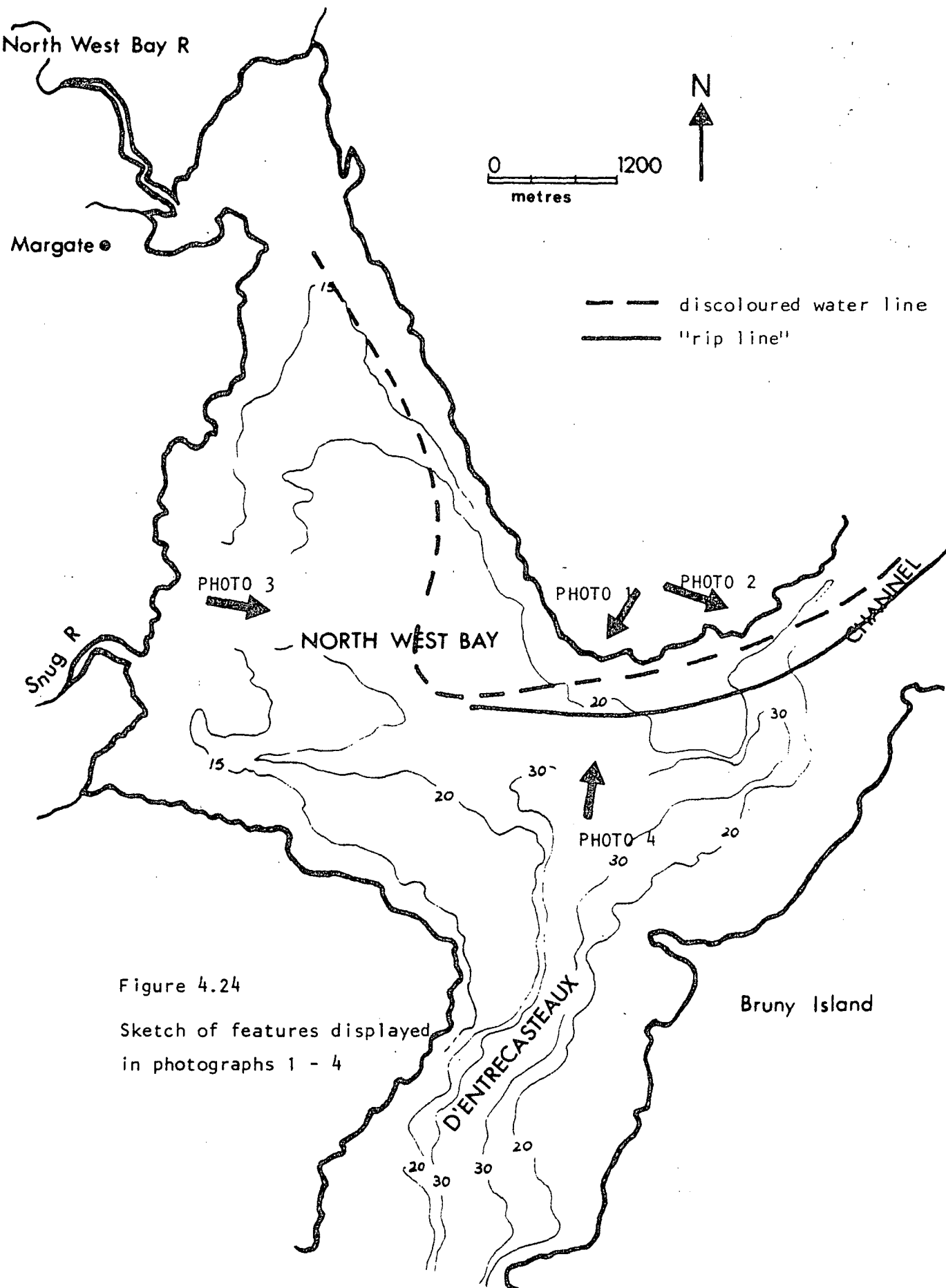
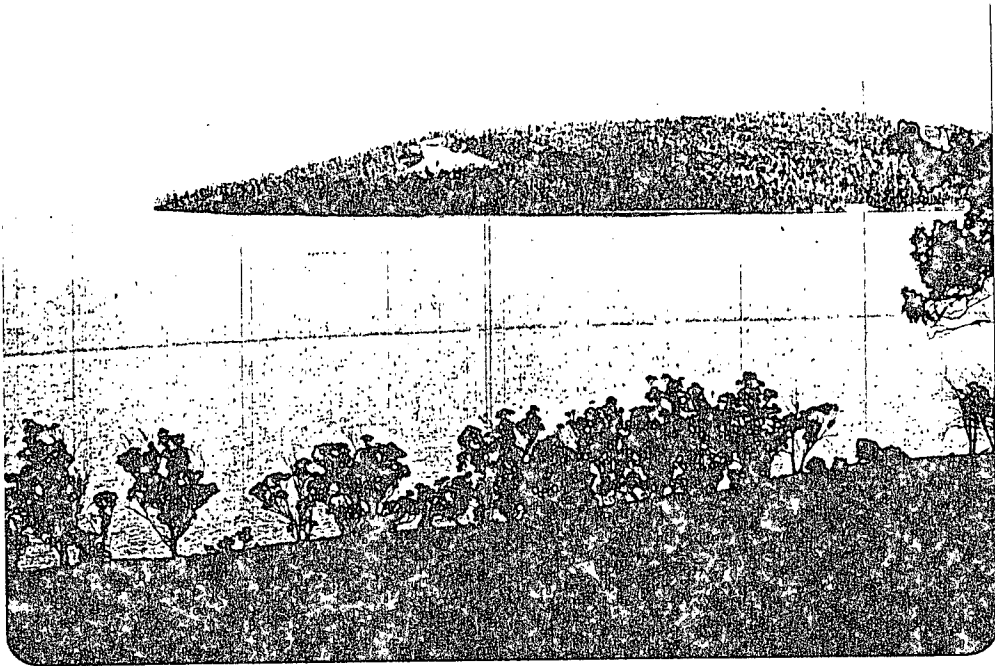


Figure 4.24

Sketch of features displayed
in photographs 1 - 4



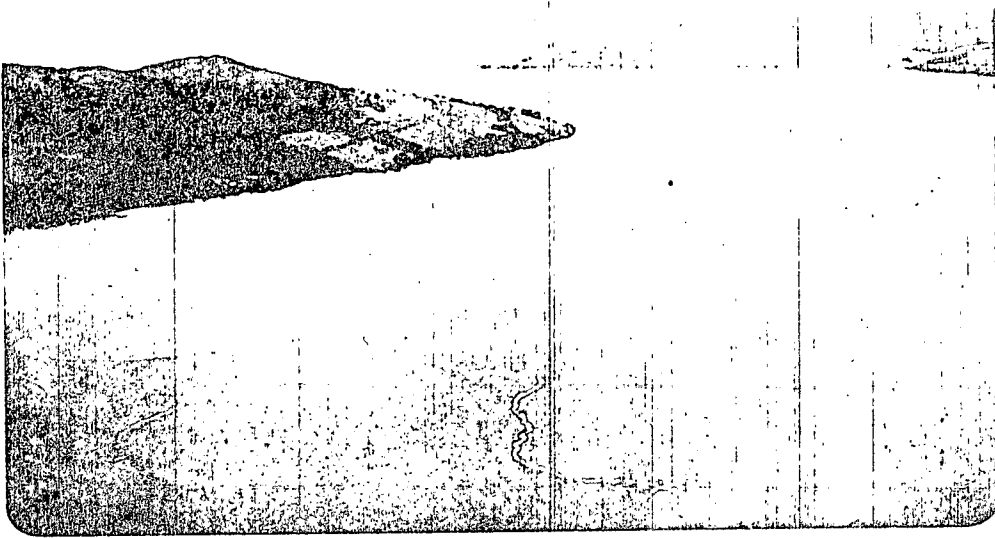
Photograph 1



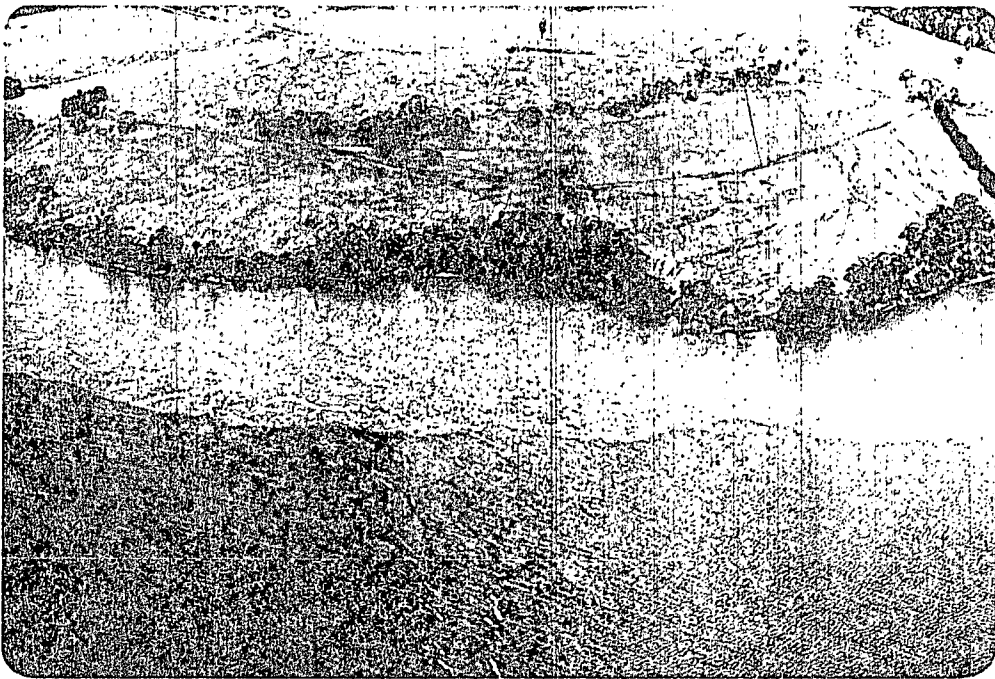
Photograph 2

Figure 4.25

Photographs of 'rip line' suggesting turbulent interface:
see Figure 4.24 for sketch and photograph aspect



Photograph 3



Photograph 4

Figure 4.26 Aerial photographs of discoloured water from
North West Bay River:
see Figure 4.24 for sketch and photograph aspects

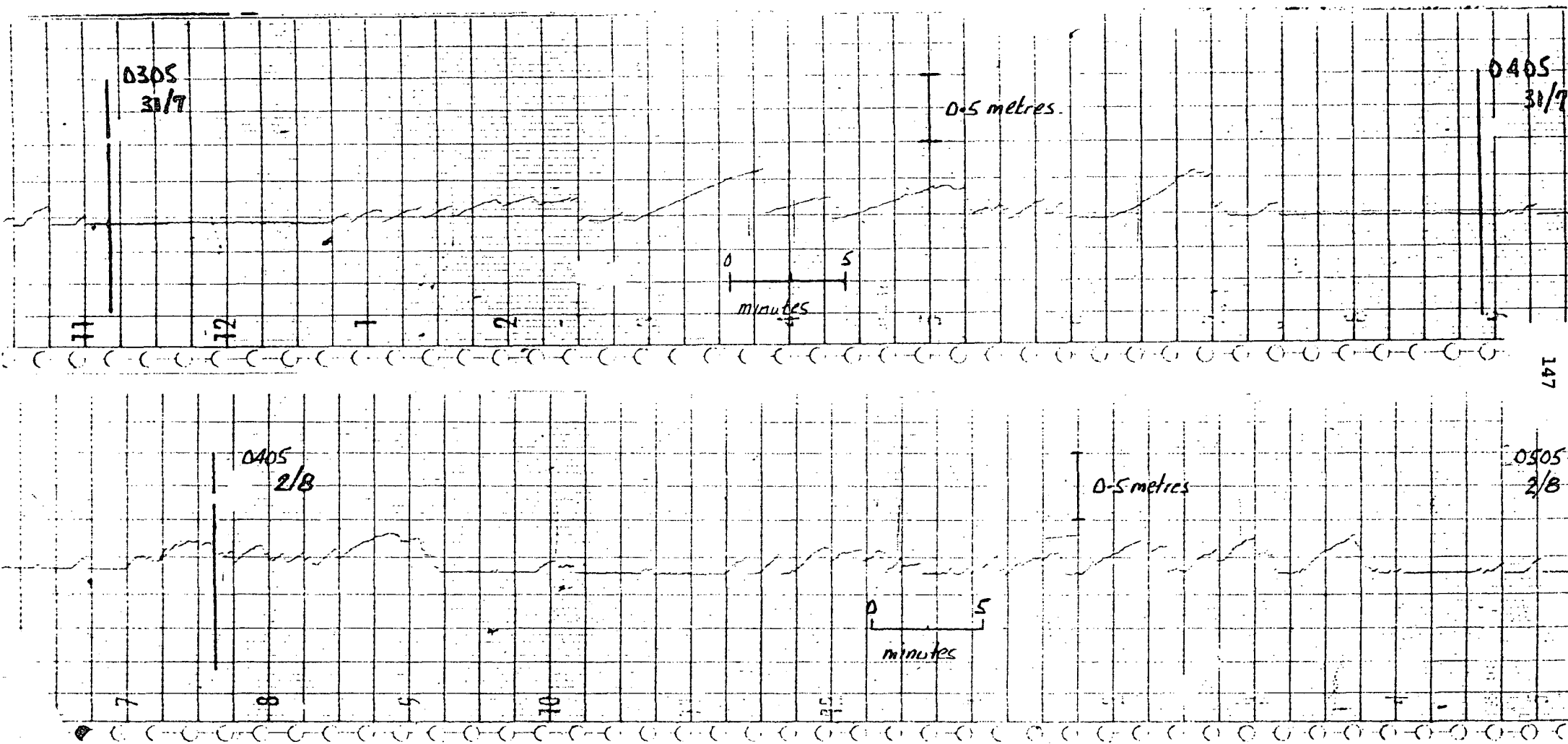
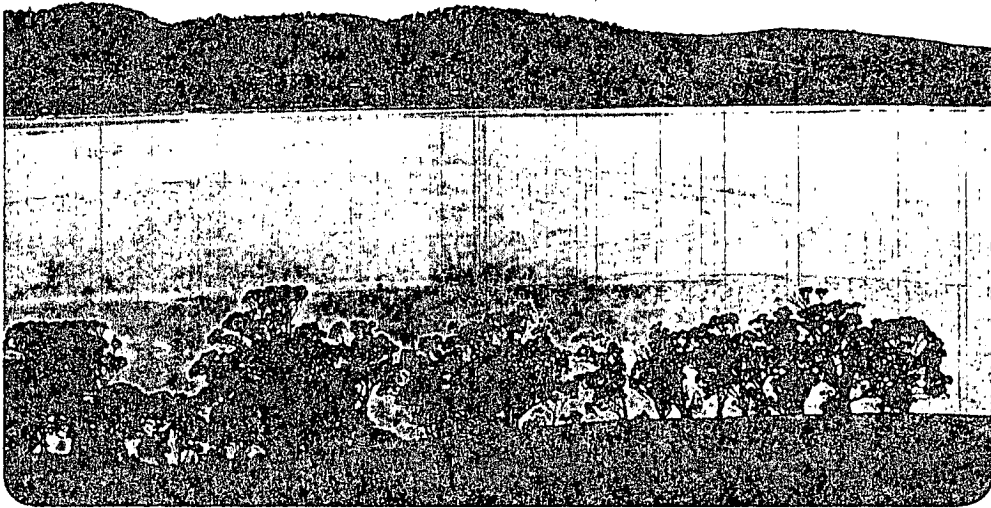


Figure 4.27

Tide record 31 July, 2 August:
showing apparent large changes in water level



Photograph 5

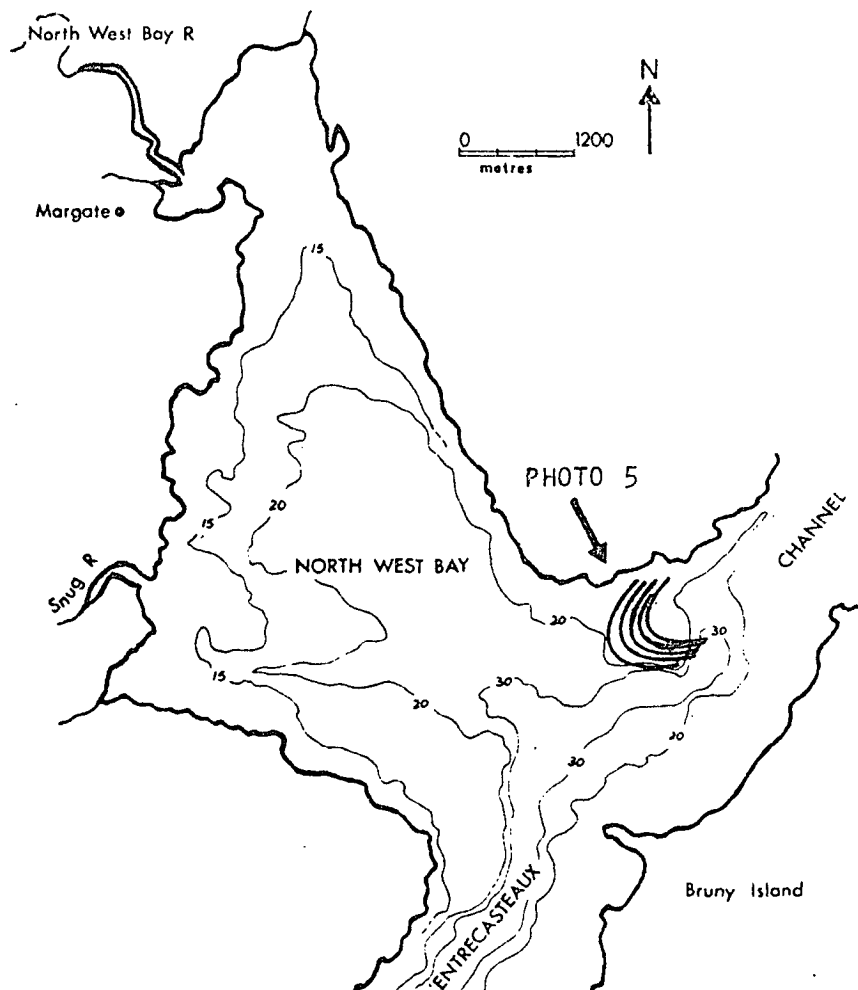


Figure 4.27

Photograph and sketch showing internal wave slicks in the D'Entrecasteaux Channel

These are characteristic of slicks formed by internal waves and indicate that these waves can occur in the area at times of strong stratification. This phenomenon could enhance vertical mixing.

4.3.4 Summary

- . The flow regime in the D'Entrecasteaux Channel may establish a circulation pattern within North West Bay with two distinct regimes. The inner (coupled) regime may contain complex eddying flows with the outer (driving) regime having well defined flow patterns.
- . Such a circulation pattern would be consistent with a higher exchange rate than expected from a consideration of the tidal prism, and would tend to enhance mixing throughout the bay.

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conclusions & implications

5. CONCLUSIONS AND IMPLICATIONS

Each section of this report has concluded with a summary highlighting important points. This concluding section brings together the important features of this study and considers the implications that can be drawn.

5.1 General

There has been concern raised in the past few years in regard to the pollution of a number of Tasmania's estuarine and coastal areas, particularly the Derwent estuary and its adjacent bays. However, the importance of studying the hydrodynamics of these systems has not been appreciated.

North West Bay is but one example of an area of environmental concern and little is known of its marine environment. This study has made a preliminary evaluation of some aspects of the hydrodynamics of North West Bay based on: an evaluation of available physical, hydrological and hydrodynamic data for the area; a review of various oceanographic methods and techniques that were suitable for use in this area; and a field investigation directed toward providing further hydrological and hydrodynamic baseline data for the area.

North West Bay is a sheltered embayment which is generally marine and little is known of its ecology, particularly the hydrology and hydrodynamics. It was the abysmal lack of information on this environmental system that prompted this research project.

The watershed of the bay is small with 67% of its area still under natural vegetation. Small urban and industrial centres are located around the shores of the bay. Because of its proximity to Hobart and its great amenity for water based activities, the area is likely to come under increased pressure for future urban and industrial development which would place increased pressures on the ecology of the bay.

At present the industrial and domestic effluent disposal schemes for the area are basic with no major centralised secondary sewage treatment scheme existing. Effluent outfalls in the bay are in poor repair and located at low water level in close proximity to bathing beaches and boating ramps or jetties.

It could be said that the deleterious effects of man's present activities are barely desirable. If future development is to occur in the catchment or along the shores of the bay, then a considerable upgrading of present disposal schemes, and the institution of a management plan for the catchment will be required if repercussions on the ecology of the bay are to be minimal.

There have been very few past studies concerned with the hydrology or hydrodynamics of the Derwent estuary, D'Entrecasteaux Channel and, in particular, North West Bay.

The hydrological information available for this study consisted of salinity-temperature data. This was obtained from other zoological studies in the area and was based on a sampling rate of one month. No data was available on the tides or circulation and flushing characteristics of North West Bay and the associated D'Entrecasteaux Channel.

Within this framework, a relatively brief field investigation was specifically aimed at providing baseline data on the hydrology and hydrodynamics of North West Bay by setting a number of specific objectives for the study. These objectives are outlined in Section 1.4 and were determined by considering the techniques and methods that were available and could be used within the constraints of this study. This involved assessing a range of techniques that were documented in the literature and, where

possible, obtaining information on commercially available equipment. In other cases, some equipment was constructed for use in the field program and in all cases the limitation and problems encountered with the techniques and methods used have been assessed in keeping with the sixth objective of this study. This evaluation has been incorporated in Section 3.

The field program was initially concerned with the consideration of a small number of variables at a particular point in the bay over short periods of time. As more equipment became available it was possible to continuously record tide levels, barometric pressure and currents within the bay while salinity-temperature, wind and drogue investigations were carried out. Not all the techniques used were successful, but the data that was obtained has brought to light some distinct and interesting features which will provide a useful background on which more detailed investigations can be based.

5.2 Specific

This section brings together the summary points presented at the end of each section of the Study Results and presents conclusions and implications in terms of the specific objectives that were outlined in Section 1.4.

Objective one:

to delineate the relative importance of the driving mechanisms from a spectral analysis of the current meter records.

Conclusions

- . Aspectral analysis of the current meter records indicates that tide is a significant driving mechanism, with the diurnal component more dominant than the semi-diurnal. Also a significant proportion of the spectral energy is contained at periods greater than 28 hours, indicating that the influence of meteorological pressure systems is important in this area.
- . Another feature of the current meter investigations has been the measurement of consistently high and sustained flows

at the entrance to North West Bay. It has been concluded that this flow is an extension of a high energy flow regime within the D'Entrecasteaux Channel. In effect, this may be considered as a driving mechanism which acts as a coupling and filtering system between North West Bay and the boundary states of the Channel.

Implications

- As the Southern Tasmanian zone is characterised by low amplitude mixed tides, the strong influence of meteorological driving forces has specific implications for other of the bays and estuaries of this area.

Since the influence of this mechanism can be expected to vary seasonally, water levels and currents within the area will have to be monitored continuously for a period of at least six months if the relative mass exchange associated with this mechanism is to be determined. Over this length of time a sampling rate of one hour would be more than adequate to produce records suitable for analysis.

The resultant circulation patterns in this area will be complex and may not be simply related to basic tidal periods. This means that, unless large numbers of current meters are available, future studies may have to be designed with limited but concise objectives in mind. In many instances it may only be possible to estimate dimensionless characteristics of these water bodies. For example, the determination of the gross mass exchange, using continuous water level recording.

- The high energy flow regime in the D'Entrecasteaux Channel, inferred from this study, means that the circulation within North West Bay may be a reflection of driving mechanisms over a wider geographic area. In this respect the discharge from the Huon estuary near the southern boundary of the channel could at times create a significant hydraulic gradient within the channel. Thus a study aimed at determining the flow patterns in the D'Entrecasteaux Channel, and their associated driving mechanisms would be of considerable importance.

Objective two:

to determine the significance of wind stress as a driving mechanism by the use of drogues.

Conclusions

- . Although wind stress investigations were limited, it was concluded that the local effect of this mechanism is restricted to the near surface layers (less than 5 metres). Hence, within the bay, wind is thought to act predominantly as a transient mixing phenomenon.
- . It was found that the surface wind drift current in the bay responds quickly to changes in wind speed and direction. Significant surface currents are produced by strong and sustained winds and long-shore drifts may develop with particular wind directions.

Implications

- . Over a wider area a significant mass transport of surface waters could occur due to the effects of wind stress. This process should be investigated in any future study aimed at determining the effect of meteorological pressure systems on the waters of the Southern Tasmanian zone.
- . A more local consideration of the effect of wind stress is its effect on sewage effluents discharged into North West Bay. At present sewage discharges are released into the surface waters of the bay and therefore very little initial dilution is achieved. Under these conditions, wind stress will play a dominant role and may distribute relatively undiluted sewage on the shores and beaches of the bay. The solution to this problem requires a more efficient level of sewage treatment and the use of deep water outfall pipes and diffusers to achieve a high initial dilution.

Objective three:

from salinity-temperature measurements to ascertain the significance of the influence of other estuarine waters on North West Bay.

Conclusions

- . The influence of coastal waters, land drainage and other local estuarine waters is apparent in the salinity-temperature data obtained in this study. While it is difficult to determine

the origin of the other estuarine waters, a number of distinctive features are worth note.

On one occasion during the study period a large increase in the freshwater content of the bay occurred. This could not be attributed to local land drainage. It was thought that this was due to the influence of estuarine waters from the Derwent River.

A consistent feature of the salinity-temperature measurements taken in the D'Entrecasteaux Channel was the decreasing salinity gradient down the channel. This was attributed to the influence of the Huon River which is the major source of fresh water in the southern part of the channel.

Implications

- . It is difficult to assess the origin of other estuarine waters that influence North West Bay solely from salinity-temperature data. Thus the use of some form of 'tracer', whether biological, chemical or physical will be required if the origins of these estuarine waters is to be conclusively determined.
- . The presence of other estuarine waters in North West Bay may have important implications. For example, this could mean that the effects of pollutants discharged into other local estuaries, and changes in their watersheds, may be felt in North West Bay. This could influence the water quality and hence the ecology of the bay.

This well illustrates the need for an understanding of the hydrology and hydrodynamics of the Southern Tasmanian zone and the role it plays in the marine ecosystem. Only from this understanding can man manage his impact on the marine environment in this area.

Objective four:

to gain some insight into the mixing mechanisms and rates of exchange between the bay and its adjacent waters.

Conclusions

- . The salinity-temperature structure of North West Bay is quite variable with distinct changes occurring in less than a week. The lack of longitudinal and later salinity gradients show

that these changes tend to be rapidly transmitted throughout the bay.

- . The daily exchange ratio has been estimated as 1:7. Although this estimate is coarse, it indicates that exchange occurs at a much greater rate than would be expected from a simple consideration of the tidal prism.

Implications

- . The variability of the salinity-temperature structure is such that a monthly sampling rate is far too coarse to monitor the changes occurring. Hence monthly data provided by previous studies essentially needs to be considered as 'spot-samples'. In general, a weekly sampling rate should be adequate to define the changes, although sampling every 2-3 days would be more desirable particularly at times when changes are occurring due to the influence of land drainage and other estuarine waters.
- . While this study indicates that fairly rapid exchange occurs, very little can be inferred about the mixing and dispersal processes within the bay. Thus it would not be appropriate to attempt to predict the behaviour of various effluents introduced into the bay on the basis of this work, which was aimed at providing background information for more specific and detailed investigations of this nature.

Objective five:

to construct some preliminary hypotheses of circulation patterns to provide a framework for future investigations.

Conclusions

- . It has been inferred that the driving regime in the D'Entrecasteaux Channel induces complex (eddy) flows in the inner or coupled regime of North West Bay, with a shear zone developed between these two regimes. This hypothesis is developed more fully in Section 4.3. Although good evidence exists for the flow patterns in the driving regime, little information has been obtained about the circulation within the inner regime.

Implications

- . It is thought that the circulation patterns hypothesised for North West Bay would enhance mixing and would account for a greater rate of exchange, between the bay and its adjacent waters, than expected simply from the tidal prism.
- . An important implication of such a circulation pattern is that other embayments along the channel may exhibit a similar 'coupled' circulation. Hence their exchange rate would also be greater than anticipated from their tidal prisms.

Objective six:

to provide a summary of a range of available oceanographic techniques and methods, and assess the values of the techniques that were used in this study.

Conclusions and Implications

- . These have been adequately made in Section 3. The important point that should be stressed is, that a wide range of techniques and methods is available and the limitations of research funds and manpower will be the most important factors in determining what will be used.

Objective seven:

to make a preliminary assessment of the possibility of mathematically modelling North West Bay.

Conclusions

- . The existence of low amplitude mixed tides and the significant effects of meteorological factors makes it very doubtful if two dimensional hydrodynamic models of circulation, and hence pollution dispersal, would be useful for studies in the Southern Tasmanian zone. The successful use of such mathematical models in overseas and Australian studies has depended upon the presence of a dominant and relatively simple tidal forcing function, where other factors are of minor importance.
- . The use of two-dimensional hydrodynamic models in North West Bay would be excluded by the inability of these models to account for the transverse shear effects which are considered to exist, in this bay, between the driving and coupled regime.

Implications

- . It is doubtful that the effort required to develop and calibrate two-dimensional models for use in the Southern Tasmanian zone would lead to any productive outcome. Hence the most productive results may well accrue from carefully designed field investigations aimed at answering specific questions.

bibliography

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appendices

APPENDIX A

The purpose of this appendix is to provide the reader with some additional background material, relating to North West Bay, that was not considered relevant to the main text.

A.1 Industry, Population and Land Use

The current population in the area is fairly small and does not appear to have grown markedly between 1971 and 1976 census. Table A.1 gives a breakdown of the population for these periods, for the townships and the catchment areas.

Table A.1
POPULATION OF THE NORTH WEST BAY WATERSHED

AREA	POPULATION	
	1971 Census	1976 Census
Snug	530	668
Margate	354	392
Electrona	243	251
Catchment Areas	N/A	1972

Paterson¹ has reviewed land use in the catchment area of the North West Bay River. Table A.2 gives the patterns of land use as interpreted from aerial photographs.

The vast majority of cleared land is used for cattle and sheep grazing with cattle grazing predominating in the lower lying areas. Areas under orchards have declined in recent years due to problems in the apple and pear industry and government incentives to uproot fruit trees. Some hop fields occur near the lower

expected as some areas in and around Margate are zoned for light industrial development and several industries have made preliminary proposals for developments in fields such as ceramics, leather-goods and granite polishing.

Sections of the area can be expected to come under considerable pressure for housing development. For example, a report by the Kingborough Council indicates that extensive subdivision is planned for the Margate/Howden area around the shoreline and adjacent to North West Bay River, Margate Rivulet and Nierinna and Coffee Creeks. Without adequate safeguards and informed management such development can be expected to pose a serious threat to the estuarine mud flats.

A.2 Soils and Vegetation

It can be seen, by referring to Table A.1 that the catchment of the North West Bay River is still relatively undeveloped, with 66% being under natural vegetation. Grauer² has carried out a detailed study of the soils and vegetation in this area. He indicates that most of the vegetation is dry sclerophyll forest, with some alpine vegetation and some wet sclerophyll forest occurring in the northernmost part of the catchment. The relative dominance of the various species of eucalypts is frequently dependent on the characteristics of the soils. These are generally podzolic and are mostly formed from the weathering of Jurassic dolerite, although soils derived from mudstones and sandstones (mostly Triassic) are also common. Some black earths (derived from Tertiary basalts), and some alluvial deposits, also occur in the lower part of the catchment. The nature of the soils, their fertility, the characteristics of the vegetation, and their relation to the hydrological regime, should be important factors in planning land use development in the area.

A.3 Recreational Potential

North West Bay has a considerable recreational potential for the people of Hobart. It is within short travelling distance, at present still maintains a rural character, and as an Australian

Senate Select Committee on Water Pollution³ points out, water is a focal point for outdoor recreation.

The area has four beaches which are described in a report by the Kingborough Council⁴. These are Snug Beach, Coningham Beaches, and the beach just east of Coningham. The last mentioned beach is totally surrounded by bushland and most of it is owned by the Lands Department. However, access to this beach is restricted by private land and a holiday camp which is presently the main user of this beach. In contrast, the other beaches are in populated areas and are used a great deal in summer months by local people as well as recreation seekers from other areas. Picnic and parking facilities are provided and Snug beach also caters for holiday visitors. An area of concern is possible pollution from the Snug river although no concrete information is available.

As previously mentioned, the bay is fairly sheltered and well suited to small boats. Launching facilities are provided at a number of locations although the best of these is at Dru Point where there is also a small reserve developed and maintained such that it is well suited for picnics.

The area around Hobart offers little potential for beach and rock fishing. Thus for the non-boat owner the explosives jetty on the eastern shore and the Safcol jetty on the western shore afford a welcome opportunity to fish. Mackerel, flathead and barracouta are the most common varieties sought in the summer, while cod are readily caught in the winter. Occasional 'runs' of other varieties such as perch, trevally and salmon occur sporadically (usually in the summer) and more than a dozen varieties of 'table fish' can be caught. Trumpeter and occasional adventitious visitors such as boarfish and ling can be taken in nets, while the mud flats offer scope for floundering and the taking of black-bream.

A.4 Waste Disposal

There is little documented material available on the use of North West Bay for waste disposal. The Carbide Works can be expected to produce some industrial effluents while the fish processing plants, undoubtedly contribute some organic wastes. More information in this area is clearly desirable.

The area of most concern is probably the disposal of human effluents since those from Snug are released near recreational beaches, while those from Margate at Dru Point in the vicinity of the estuarine mud flats. No information on the discharges at Snug could be found, however Scott and Furphy⁵ indicate that the effluent at Margate is treated to primary level and the daily discharge is 90 cubic metres per day, with the sludge being disposed of on land (site not mentioned). Perry⁶ has studied faecal coliforms in the vicinity of the outfall and concluded that the Kingborough Council may be violating the Environmental Protection Act⁷ by permitting a discharge considerably higher than the allowable coliform concentration.

A.5 Administrative Control and Management

The final consideration that arises is that of management. The North West Bay watershed currently comes under three separate spheres of influence. The eastern section is in the Kingborough Municipality, the western section is in the Huon Municipality, and the northern section although actually split between these municipalities is part of the Metropolitan Water Board Reserve. No industrial, residential, or agricultural development can take place in the reserve.

At the moment most of the development pressures are in the Kingborough Municipality and thus to a large degree it can be argued that this Municipality presently has effective control. However it seems reasonable to assert that a watershed is better managed as a single unit. Thus it would be desirable if some co-ordinating body could be formed so that the three participants, and the two councils in particular, can form common management aims and strategies.

reaches of the North West Bay River, although their future is in doubt due to pressures of housing development. Some small fruits cultivation occurs in small areas near the Huon highway.

Table A.2
PATTERNS OF LAND USE IN THE NORTH
WEST BAY RIVER CATCHMENT¹

NATURE OF LAND USE	AREA (km ²)	%
Residential:		
developed	1.10	0.06
under development	0.74	0.4
Industrial	0.11	0.1
Public Open Space	0.72	0.4
Intensive Agriculture	2.14	1.2
Extensive Agriculture (cleared areas)	55.12	31.0
Quarries	0.05	-
Natural Vegetation	117.96	66.3
TOTAL	177.96	100.0

Most of the farm holdings are small and it is estimated that only about half of the farm owners make their living exclusively from their land. One of the most significant developments in the area has been the advent of the weekend or hobby farmers who own approximately one third of the farm holdings in the area.

Industrial land use is at present dominated by a carbide factory at Electrona which employs about 170 people and is operated by Tasmanian Carbide Products. Other minor light industries which exist at present include fish processing factories (Safcol and Gourmet), a body works, earthmoving and haulage contractors (Hazell Bros.) and a few small quarries periodically operated by local councils. However these establishments have a significant impact on the character and the economy of the area. Apart from farming, other commercial enterprises are limited to Real Estate Agents, some small shops and service agencies, commercial fishermen, and some oyster and mussel farming. However some growth can be

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APPENDIX B

DAILY CLIMATOLOGICAL DATA, HOBART
(Bureau of Meteorology)

MAY - SEPTEMBER 1977

- . Rainfall
- . Temperature ranges
- . Wind speed and direction

MONTH : May 1977

Day	Rainfall (mm)	Temperature °C		Wind (hourly readings)	
		Max	Min	Mean Speed (km h ⁻¹)	Predominant Direction
01	-	14.6	09.6	14.2	sw
02	-	15.7	04.7	7.6	nw/wsw
03	-	18.4	05.9	7.5	nw
04	-	13.6	05.0	7.7	nw
05	-	19.8	05.8	7.1	nw
06	04.2	16.6	10.2	10.3	nw
07	-	14.0	06.2	6.4	nnw/w
08	-	15.1	08.5	5.7	n/nw/wnw
09	00.8	16.2	06.2	7.0	n
10	06.0	13.0	06.7	9.4	nw
11	00.2	10.8	03.5	8.2	nnw
12	00.2	13.9	04.6	4.2	nw
13	-	17.4	07.7	11.8	nnw
14	-	15.2	05.9	7.9	nnw
15	-	12.8	06.5	10.3	s
16	-	12.0	03.0	9.1	nnw
17	-	13.2	04.8	7.2	n
18	01.4	13.4	08.9	3.3	n
19	-	15.2	07.1	7.5	nnw
20	00.6	15.5	08.5	6.0	n
21	03.0	13.5	09.4	11.9	n-nw
22	00.8	13.3	06.0	15.1	sw
23	03.8	10.8	08.5	7.9	-
24	03.6	11.7	08.2	4.8	ssw
25	10.0	10.5	06.8	6.9	sw-s
26	-	12.8	03.4	8.0	nw
27	-	14.3	04.5	10.0	nnw-nw
28	00.2	12.6	08.3	16.3	nw-sw
29	00.6	14.0	06.6	15.0	n-nw
30	00.6	12.2	08.5	15.3	nw
31	00.8	10.7	04.5	10.2	nw

MONTH : June 1977

Day	Rainfall (mm)	Temperature °C		Wind (hourly readings)	
		Max	Min	Mean Speed (km h ⁻¹)	Predominant Direction
01	02.0	11.0	05.3	16.0	sw
02	-	14.2	04.6	14.2	nw/w
03	00.4	13.7	09.4	10.9	sw
04	-	12.6	04.0	8.0	w/nnw
05	-	10.9	03.7	5.6	nw/nnw
06	00.2	11.7	01.8	11.0	nnw
07	-	10.6	01.9	13.5	nnw
08	00.2	10.5	05.5	3.3	ssw
09	00.2	09.9	04.8	11.4	sw
10	-	11.6	03.6	8.9	nw/nnw
11	-	10.6	03.9	4.8	nw
12	-	12.5	04.2	5.2	ws
13	-	14.1	07.0	10.1	nw/nnw
14	00.2	16.1	09.6	14.4	nnw
15	00.4	14.1	07.1	11.0	nw/nnw
16	02.8	11.8	06.1	5.8	ws-ese
17	01.8	11.8	07.9	3.5	n/nnw
18	00.4	11.5	06.4	4.8	n-nw-s
19	00.2	13.7	07.0	4.4	ene-nw-ssw
20	00.2	14.1	05.1	5.0	nnw-ww
21	-	13.8	05.1	5.7	nnw-wnw
22	-	14.5	03.3	5.3	nw-ww
23	-	10.0	05.2	10.9	nw
24	-	10.5	04.5	7.4	nnw-s
25	11.0	10.9	05.0	13.4	s
26	02.6	12.7	07.6	15.3	s-nw-n
27	-	12.0	04.8	7.1	nnw
28	00.4	09.2	04.4	14.8	nw
29	00.4	10.3	03.9	9.4	nw
30	18.6	06.3	03.5	19.2	s
31					

MONTH : July 1977

Day	Rainfall (mm)	Temperature °C		Wind (hourly readings)	
		Max	Min	Mean Speed (km h ⁻¹)	Predominant Direction
01	06.0	12.7	01.1	9.6	nnw-sw
02	-	14.0	04.0	8.7	nnw-wsw
03	00.2	11.4	02.8	8.0	nnw/nw
04	-	14.0	02.8	11.1	nnw-wsw-se
05	-	14.7	04.1	5.5	nw-wsw
06	-	12.8	03.5	6.3	nw
07	00.2	15.2	04.4	7.2	nw
08	-	13.0	05.2	7.3	nnw/nw
09	-	12.2	04.5	8.2	nw
10	-	10.4	03.8	10.6	nw
11	00.4	12.7	04.3	11.8	nw/wsw
12	-	11.7	02.5	4.9	nw
13	-	12.5	03.5	9.7	nnw
14	08.8	10.2	04.2	16.5	ssw
15	09.2	10.9	05.7	31.8	s
16	02.2	11.5	06.8	15.8	s
17	02.0	08.3	05.5	10.7	ssw
18	-	07.6	02.5	5.2	nnw/nw
19	-	06.7	01.2	7.7	nnw/nw
20	-	08.9	00.5	11.4	nnw/nw
21	00.2	10.5	00.4	12.7	nnw/nw
22	00.2	14.7	01.8	15.2	nnw
23	00.2	12.1	05.7	12.1	n-nw
24	-	09.9	05.3	20.3	nnw
25	01.0	10.7	05.0	21.6	n
26	-	09.4	04.7	13.1	nnw/nw
27	02.8	11.8	05.4	16.4	nw
28	14.2	10.7	05.5	15.2	ssw
29	14.4	10.4	05.4	8.6	nnw/nw
30	01.6	10.7	03.3	4.9	nnw-wsw
31	-	10.8	01.8	6.6	nw

MONTH : August 1977

Day	Rainfall (mm)	Temperature °C		Wind (hourly readings)	
		Max	Min	Mean Speed (km h ⁻¹)	Predominant Direction
01	00.2	12.8	03.8	8.2	nnw
02	00.4	13.0	03.7	5.8	nw
03	00.4	11.7	04.7	6.8	n/nw
04	00.8	15.4	06.1	4.2	nnw
05	-	15.4	06.2	10.8	nnw
06	00.2	13.6	05.6	12.4	nnw
07	00.6	10.0	06.2	9.6	sw
08	00.4	11.3	05.7	8.9	-
09	-	14.0	02.2	9.6	nw
10	-	17.7	04.0	9.7	nw
11	-	19.8	07.6	11.3	nnw
12	00.2	15.6	08.7	29.2	nnw-wnw
13	-	13.0	06.6	15.4	wsn
14	-	11.6	05.0	6.7	nnw/nw
15	-	13.0	07.8	14.5	nnw-w
16	05.4	13.2	05.8	17.2	nnw/wsw
17	-	15.5	05.2	16.1	nnw/nw
18	00.4	13.1	07.7	17.9	nw
19	-	16.3	04.0	11.2	nnw/nw
20	00.6	14.8	05.2	18.6	nnw-wnw
21	02.4	09.5	06.2	21.8	nnw-wnw
22	03.0	13.9	03.7	10.8	nnw
23	00.0	17.7	06.7	13.3	nnw
24	00.8	17.4	03.8	15.5	nw
25	00.0	23.8	06.9	8.7	nnw
26	00.0	24.5	09.8	12.7	nw
27	00.8	11.7	07.0	17.4	wsn-ssw
28	00.0	13.4	01.8	9.2	n/nnw
29	01.2	16.4	05.0	17.0	nnw
30	00.0	13.6	06.7	10.2	nnw-wsn
31	00.0	13.8	04.9	6.9	ssw

MONTH : September 1977

Day	Rainfall (mm)	Temperature °C		Wind (hourly Readings)	
		Max	Min	Mean Speed (km h ⁻¹)	Predominant Direction
01	-	11.9	04.1	9.3	nnw-s
02	00.4	10.9	04.2	8.1	nnw/nw/se
03	-	11.0	04.5	7.7	nnw/ssw
04	06.6	11.1	02.8	13.8	sw
05	00.2	13.2	02.2	7.9	wsn/nnw
06	09.0	09.9	06.3	9.7	sw-sse
07	05.8	15.0	04.8	8.2	nnw

APPENDIX C

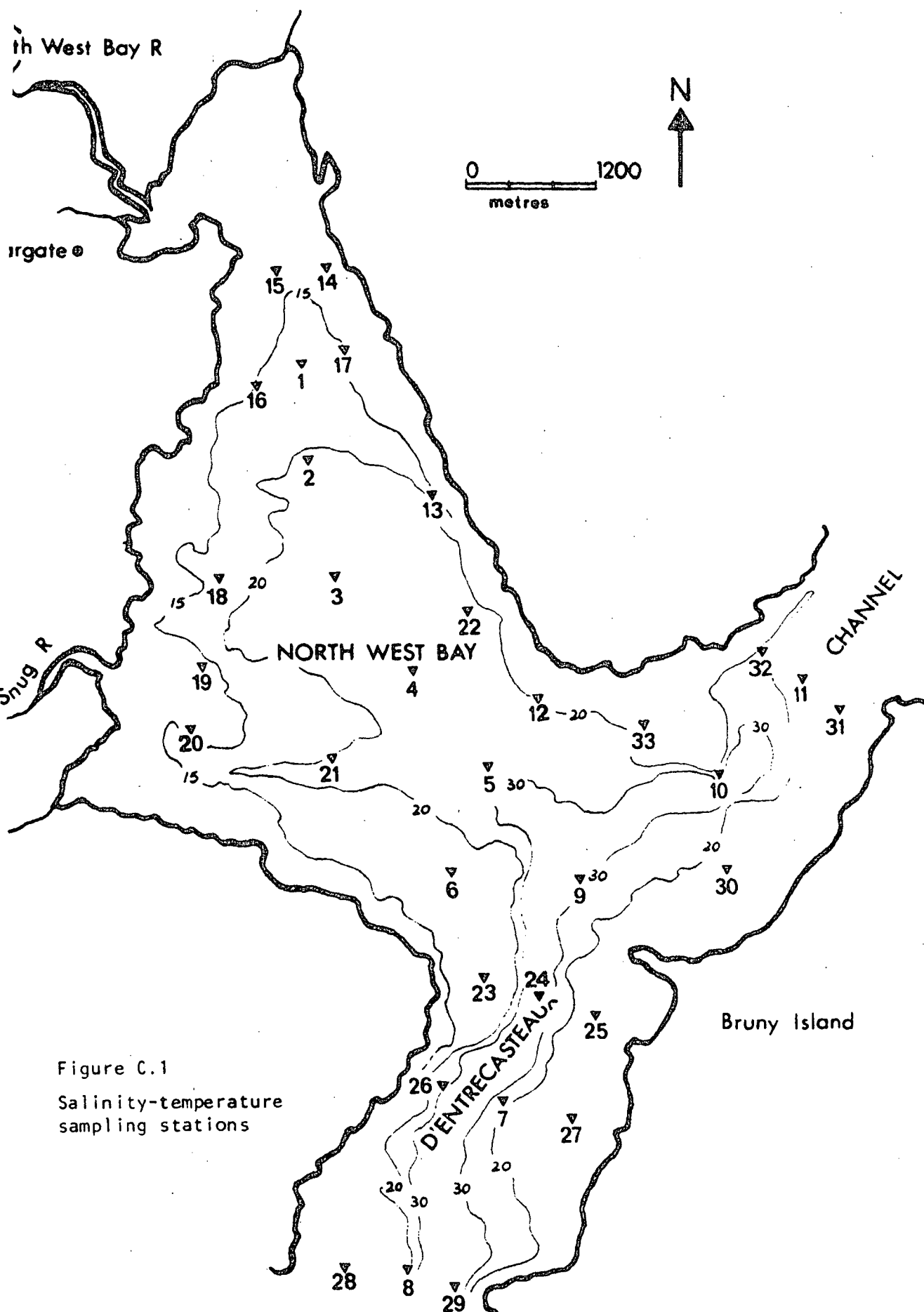
SALINITY-TEMPERATURE MEASUREMENTS

North West Bay

and

D'Entrecasteaux Channel

MAY - SEPTEMBER 1977



DATE : 19/5/77

[illegible]

[illegible]

DATE : 24/5/77

[illegible]

DATE : 24/5/77

[illegible]

DATE : 4/6/77

STATION NUMBER													
Depth (metres)	1	2	3	4	5	6	7	8	9	10	11	12	13
S	S ‰										34.5		
	T °C										11.5		
0.5	S ‰	34.0	34.0	34.0	34.0	34.2	34.0	33.5	33.1	34.5	34.0	34.4	33.8
	T °C	11.2	11.3	11.5	11.5	11.5	11.8	11.6	11.2	11.8	11.6	11.6	11.0
2	S ‰	34.0	34.0	34.0	34.0	34.2	34.0	33.4	33.1	34.2	34.1	34.5	34.1
	T °C	11.3	11.5	11.2	11.3	11.5	11.8	11.5	11.2	11.8	11.7	11.7	11.2
5	S ‰	34.0	34.0	34.0	34.0	34.5	34.0	33.8	33.2	34.0	34.1	34.8	34.1
	T °C	11.5	11.3	11.2	11.5	11.7	11.8	11.5	11.3	11.9	11.8	11.7	11.2
8	S ‰	34.0	34.0	34.0	34.0	34.1	34.0	33.9	33.5	34.0	34.2	34.5	34.0
	T °C	11.5	11.3	11.3	11.5	11.7	11.8	11.5	11.2	11.9	11.8	11.9	11.5
11	S ‰	34.0	34.0	34.1	34.0	34.0	34.0	33.9	33.5	34.1	34.5	34.5	34.0
	T °C	11.5	11.3	11.3	11.5	11.7	11.9	11.5	11.5	11.9	11.8	11.9	11.7
14	S ‰	34.0	34.2	34.0	34.1	34.2	34.0	33.9	33.5	34.1	34.4	34.5	34.1
	T °C	11.5	11.3	11.5	11.6	11.7	11.9	11.8	11.6	12.0	11.9	11.9	11.8
17	S ‰	34.1	34.0	34.1	34.0	34.1	34.0	34.0	33.5	34.2	34.5	34.5	34.1
	T °C	11.5	11.4	11.5	11.6	11.6	11.9	11.8	11.6	12.0	11.9	11.9	11.8
20	S ‰		34.1	34.2	34.1	34.2	34.0	34.0	33.6	34.2	34.5	34.5	34.0
	T °C		11.5	11.5	11.6	11.6	11.9	11.9	11.6	12.0	11.9	11.9	11.8
25	S ‰				34.5	34.2				34.2	34.5	34.5	34.0
	T °C				11.7	11.7				12.0	11.9	11.9	11.8
27	S ‰					34.2				34.3	34.5	34.5	34.0
	T °C					11.8				12.0	11.9	12.0	11.8

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STATION NUMBER													
Depth (metres)	14	15	16	17	18	19	20	21	22	23	24	25	26
S	S ‰												
	T °C												
0.5	S ‰	33.8								34.0	34.0	34.0	33.3
	T °C	11.4								11.6	11.2	11.5	11.2
2	S ‰	33.8								34.0	34.0	33.9	33.3
	T °C	11.6								11.6	11.2	11.2	11.1
5	S ‰	33.8								34.0	34.1	34.0	33.4
	T °C	11.5								11.6	11.2	11.3	11.0
8	S ‰									34.0	34.0	34.0	33.6
	T °C									11.7	11.2	11.2	11.0
11	S ‰									34.1	34.0	34.0	33.8
	T °C									11.8	11.4	11.5	11.5
14	S ‰									34.0	34.0	34.0	33.9
	T °C									11.9	11.4	11.6	11.6
17	S ‰									34.0	34.0	34.2	33.8
	T °C									11.9	11.5	11.8	11.6
20	S ‰									34.0	34.1	34.1	33.8
	T °C									11.9	11.8	11.8	11.6
25	S ‰									34.0	34.0	34.0	
	T °C									12.0	11.9	11.9	
27	S ‰									34.0	34.0	34.0	
	T °C									12.0	11.9	11.9	

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		STATION NUMBER											
Depth (metres)		27	28	29	30	31	32	33					
5	S ‰					34.4							
	T °C					11.7							
0.5	S ‰	33.9	33.0	33.3	33.5	34.4	34.2	34.0					
	T °C	11.5	11.3	11.5	11.7	11.7	11.0	11.2					
2	S ‰	33.7	33.0	33.6	33.9	34.6	34.0	34.2					
	T °C	11.5	11.2	11.3	11.6	11.5	11.5	11.5					
5	S ‰	33.8	33.0	33.7	34.0	34.5	34.3	34.1					
	T °C	11.2	11.1	11.3	11.8	11.2	11.7	11.6					
8	S ‰	34.0	33.0	33.7	34.0	35.0	34.3	34.0					
	T °C	11.2	11.1	11.5	11.8	11.2	11.7	11.7					
11	S ‰	34.0	33.0	33.7	34.1	35.1	34.5	34.2					
	T °C	11.5	11.1	11.4	11.8	11.3	11.8	11.7					
14	S ‰	33.8	33.0	33.7	34.2	34.9	34.8	34.0					
	T °C	11.6	11.1	11.5	11.9	11.5	11.8	11.8					
17	S ‰		33.1	33.7		34.9	34.6	34.0					
	T °C		11.2	11.4		11.7	11.8	11.9					
20	S ‰		33.2	33.7		35.0	34.6	34.0					
	T °C		11.5	11.4		11.7	11.8	11.9					
25	S ‰			33.7		35.0	34.6	34.2					
	T °C			11.4		11.6	11.8	11.9					
27	S ‰			33.7		35.0	34.8	34.5					
	T °C			11.4		11.6	11.8	11.9					

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		1	2	3	4	5	6	7	8	9	10	11	12	13
5	S %													
	T °C													
.5	S %	33.5	33.7	33.8	33.9	33.3	33.9	33.5	33.4	33.5	33.8	33.5	33.5	33.5
	T °C	10.1	10.0	10.0	10.0	10.4	10.0	10.3	10.5	10.2	10.3	10.8	10.0	10.0
2	S %	33.7	33.4	33.7	33.5	34.3	34.8	33.5	33.5	33.5	33.9	33.3	33.5	34.0
	T °C	10.2	10.0	10.0	10.0	10.4	10.2	10.4	10.7	10.2	10.3	10.5	10.0	10.0
5	S %	33.9	33.8	33.5	33.5	35.0	34.0	33.9	33.8	33.3	35.0	34.0	33.8	33.5
	T °C	10.2	10.0	10.1	10.1	10.1	10.2	10.4	10.8	10.5	10.5	10.5	10.0	10.0
8	S %	33.5	33.8	33.8	33.5	34.0	35.0	34.0	34.0	33.5	34.1	34.1	33.2	34.2
	T °C	10.1	10.1	10.0	10.0	10.1	10.3	10.8	10.8	10.6	10.9	10.5	10.0	10.0
1	S %	34.2	34.1	34.0	34.0	34.1	34.0	34.7	33.5	34.0	34.1		34.1	34.0
	T °C	10.8	10.8	10.7	10.0	10.0	10.8	11.0	10.8	10.8	11.0		10.1	10.3
4	S %	34.1	34.0	34.3	33.9	34.1	34.2	34.2	34.5	34.5	34.1	35.1	33.8	34.1
	T °C	11.0	11.0	11.0	11.0	10.8	11.0	11.0	11.0	11.1	11.0	11.5	10.2	11.0
7	S %	35.0	34.3	34.6	34.0	34.5	35.0	34.3	34.4	34.5	34.1		34.0	35.2
	T °C	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.5	11.1		11.0	11.0
0	S %		34.6	34.7	34.0	35.1	35.0	34.5	34.0	35.0	34.5		34.6	
	T °C		11.0	11.0	11.0	11.0	11.0	11.0	11.3	11.8	11.2		11.0	
5	S %					35.2		34.3		35.2	35.0		34.5	
	T °C					11.6		11.1		12.0	11.5		11.1	
7	S %							34.5		35.1	35.2		34.5	
	T °C							11.2		12.0	11.6		11.1	

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Depth (metres)	15	17	22	24									
S	S ‰												
	T °C												
0.5	S ‰	33.5	33.8	33.5	33.7								
	T °C	10.1	10.2	10.1	10.1								
2	S ‰	34.0	33.5	33.5	33.8								
	T °C	10.1	10.3	10.2	10.1								
5	S ‰	33.4	34.0	34.0	34.2								
	T °C	10.1	10.5	10.2	10.2								
8	S ‰		34.5	33.5	34.1								
	T °C		10.8	10.2	10.6								
11	S ‰		34.0	34.0	34.2								
	T °C		11.0	10.5	10.6								
14	S ‰		34.9	34.2	34.5								
	T °C		11.0	11.0	11.0								
17	S ‰			34.1	34.4								
	T °C			11.0	11.0								
20	S ‰			34.4	35.0								
	T °C			11.2	11.0								
25	S ‰			35.0	35.0								
	T °C			11.7	11.5								
27	S ‰				35.2								
	T °C				11.9								

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STATION NUMBER														
Depth (metres)		1	2	3	4	5	6	7	8	9	10	11	15	24
S	S ‰	33.6	33.5	33.5	33.2	33.2				33.5	33.4		33.5	33.4
	T °C	9.9	9.9	10.1	10.3	10.6				10.5	10.5		9.2	10.2
0.5	S ‰	33.6	33.5	33.4	33.3	33.2				33.6	33.4		33.4	33.4
	T °C	9.9	9.9	10.2	10.3	10.5				10.5	10.5		9.5	10.1
2	S ‰	34.2	33.6	33.3	33.4	33.3				33.8	33.4		33.8	33.4
	T °C	10.0	10.0	10.1	10.1	10.5				10.5	10.5		10.0	10.1
5	S ‰	34.4	33.6	33.5	33.8	33.4				33.9	33.6		34.1	33.5
	T °C	10.0	10.0	10.2	10.0	10.5				10.5	10.5		10.1	10.1
8	S ‰	34.4	33.9	33.6	33.9	33.5				34.3	34.0			33.9
	T °C	10.0	10.0	10.5	10.5	10.6				10.7	10.5			10.2
11	S ‰	34.4	34.8	33.5	34.2	33.9				34.3	34.1			33.9
	T °C	10.0	10.0	10.8	10.5	10.7				10.8	10.7			10.5
14	S ‰	34.7	34.6	33.5	34.1	34.1				34.3	33.3			33.9
	T °C	10.1	10.0	11.0	10.8	11.0				11.0	11.0			10.8
17	S ‰	34.9	34.9	33.9	34.4	34.4				34.5	34.9			34.0
	T °C	10.3	10.0	11.0	11.0	11.0				11.0	11.0			11.0
20	S ‰		34.9	34.4		34.6				34.9	34.7			34.4
	T °C		10.5	11.0		11.2				11.1	11.2			11.0
25	S ‰					34.9				34.9	35.2			34.6
	T °C					11.7				11.5	11.5			11.4
27	S ‰										35.3			
	T °C										11.7			

DATE : 19/7/77

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DATE : 30/7/77

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DATE : 2/8/77

[illegible]

DATE : 6/8/77

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DATE : 9/8/77

[illegible]

[illegible]

DATE : 7/9/77

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